AN ONTOLOGY—SUPPORTED TRANSACTION FORMALISM PROTOCOL IN INFRASTRUCTURE MANAGEMENT

by

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Abstract

Infrastructure organizations use diversified information systems to exchange data (transaction). Presently, data exchange in the area of infrastructure management is accomplished in a manual and *ad hoc* basis. The growing trend is to transform these manual data exchanges to a computer-to-computer based transactions. The core research questions include:

What transactions are candidates to formalize?—this question is dealt with identifying and selecting a potential transaction for IT improvement—Asset Inventory and Condition Assessment Reporting/Tangible Capital Asset (AI&CAR/TCA) Reporting.

Why formalize transactions?”—this question is dealt with developing and applying an Infrastructure Management—Process Maturity Model to assess the degree to which work processes and communications are formalized in infrastructure management. The results indicate that the work processes and communications are currently performed on an *ad hoc* basis.

How to formalize and manage transactions?— this question is dealt with developing and applying an ontology-supported Transaction Formalism Protocol (TFP), which is composed of two parts: ontology and protocol. Two ontologies, the Transaction Domain Ontology and Tangible Capital Asset ontology, were developed to represent transaction domain knowledge and Tangible Capital Asset knowledge respectively to support the design, management, and implementation of transactions in infrastructure management. Moreover, an eight-step procedure—the TFP was developed from two perspectives: The TFP Specification modeled each step of the protocol as a function for which inputs, controls, mechanisms, tools/techniques, and outputs were defined, whereas the TFP Tool includes a set of forms and guidance developed for specific steps of the protocol.

The proposed TFP was applied to develop transaction specification for the AI&CAR/TCA Reporting, which was managed and implemented through developing the Infrastructure Transaction Management Portal and Asset Information Integrator System repectively.

The evaluation results indicate that both the ontologies are consistent, concise, complete, correct, and clear. Similarly, the protocol was found to be feasible, usable, useful, and generic. The major contributions include the development of two ontologies and protocol, whereas the medium contributions are: IT use survey, development of the IM-PMM, portal, and asset integrator information system. The minor contribution; however, includes the development of the transaction specification for the AI&CAR/TCA Reporting.

Preface

A component of this Ph.D. research work provided part of the Semantic Collaborative Portal for the Exchange of Infrastructure Interdependencies Information (SCPEI3) project under the Joint Infrastructure Interdependency Research Program (JIIRP), which is accomplished jointly by the research students at the University of Toronto and the University of British Columbia.

The core focus of this research work is on the development and application on an ontology-supported transaction formalism protocol that transaction development personnel can use to define transactions for IT improvement in the domain of infrastructure management. The author of this research work is solely responsible for all the content presented in this manuscript-based thesis that relates to the literature review, research framework, case study, IT survey, development and application of the Infrastructure Management–Process Maturity Model, development and application of the Transaction Domain Ontology and Tangible Capital Asset Ontology, development and application of the Transaction Formalism Protocol, development of the prototype Infrastructure Transaction Management Portal, and development and application of the prototype Asset Information Integrator Systems.

Much of the content of this dissertation is in the form of manuscripts prepared for publication. For each of these, the dissertation author (Zeb) was the primary manuscript author, while the other co-authors provided guidance on the development and application of various aspects of the research as well as manuscript review and editing.

The following six journal papers have either been accepted or published:

i. Zeb, J.; Froese, T.; and Vanier, D. (2014). " An Ontology-Supported Asset Information Integrator System in Infrasturcture Management", Accepted for Publication, Built Environment Project and Asset Management, Emerald Publishing Inc.

ii. Zeb, J. and Froese, T. (2014). "Tangible Capital Asset Ontology in Infrastructure Management", Infrastructure Asset Management Journal, Vol. 1, Issue 3, Institution of Civil Engineers, ICE Publishing, United Kingdom, pp. 81-92, http://dx.doi.org/10.1680/iasma.14.00012

iii. Zeb, J. and Froese, T. (2014). "Infrastructure Management Transaction Formalism Protocol Specification: A Process Development Model", Construction Innovation: Information, Process, Management Journal, Volume 14, Issue 1, pp. 69-87.

iv. Zeb, J.; Froese, T.; and Vanier, D. (2013). "Infrastructure Management Process Maturity Model: Development and Testing", Journal of Sustainable Development, Vol. 6, Issue No. 11, Published by Canadian Center of Science and Education, http://doi:10.5539/jsd.v6n11p1.

v. Zeb, J.; Froese, T.; and Vanier, D. (2012). "Survey of Information Technology Use for Municipal Infrastructure Management", Journal of Information Technology in Construction, Vol. 17, pp. 179-193, http://www.itcon.org/2012/11.

vi. Zeb, J. and Froese, T. (2012). “Transaction Ontology in the Domain of Infrastructure Management”, Canadian Journal of Civil Engineering, Vol. 39, Issue 9, Published by NRC Research Press, pp. 993-1004, doi:10.1139/L2012-054.

Chapter 7 and 8 contain journal manuscripts that have been submitted for publication:

i. Zeb, J. and Froese, T. (2014). “Transaction Formalism Protocol Tool in Infrastructure Management”, Submitted for Publication.

ii. Zeb, J. and Froese, T. (2014). “An Ontology-Supported Infrastructure Transaction Management Portal”, Submitted for Publication.

The following peer-reviewed conference papers have been published in the conference proceedings:

i. Zeb, J.; Froese, T.; and Vanier, D. (2014). “Knowledge Enabled Tangible Capital Asset Reporting Using Asset Information Integrator System in Infrastructure Management”, Genernal Conference, Canadian Society of Civil Engineering, May 28-31, 2014, Halifax, Nova Scotia, Canada, pp. GEN-17-1~10.

ii. Zeb, J. and Froese, T. (2013). “Transaction Formalism Protocol in the Domain of Infrastructure Management”, Siamak Yazdani and Amarjit Singh (Eds.), New Developments in Structural Engineering and Construction, Research Publishing Services, C-34-271, Seventh International Structural Engineering and Construction Conference (ISEC-7), June 18-23, 2013, Honolulu, Hawaii, USA.

iii. Zeb, J. and Froese, T. (2013). “Tangible Capital Asset Ontology Towards Standardized Reporting in Infrastructure Management”, 4th Construction Specialty Conference, Canadian Society of Civil Engineering, May 29-June 1, 2013, Montreal, Quebec, pp. CON-090-1~10.

iv. Zeb, J.; Froese, T.; and Vanier, D. (2012). “A Review of the Process Formalization Standards to Develop a Transaction Protocol for Infrastructure Management”, Gudnason & Scherer (Eds.), eWork and eBusiness in Architecture, Engineering and Construction, © 2012 Taylor & Francis Group, 9th European Conference on Product and Process Modeling (eCPPM 2012), July 25-27, 2012, Reykjavik, Iceland, pp. 405~412.

v. Zeb, J.; Froese, T.; and Vanier, D. (2011). “Development and Testing of a Process Maturity Model in the Domain of Infrastructure Management”, Proceedings of the CIB W78–W102, October 26-28, 2011, Sophia Antipolis, France.

vi. Zeb, J. and Froese, T. (2011). “Design and Management of Transactions in the AEC/FM Industry Using an Ontological Approach”, 3rd International/9th Construction Specialty Conference, Canadian Society of Civil Engineering, June 14-17, 2011, Ottawa, ON, pp. CN-021-1~10.

A peer-reviewed book chapter has been accepted for publication.

i. Zeb, J. and Froese, T. (2014). “Transaction Formalization in the Infrastructure Management Using an Ontological Approach”, Techncial Book Chapter Accepted for Publication in the ASCE Ontology Monograph Book Titled “Ontology in the AEC domain: A Decade of Research and Developments.”

Finally, two manuscripts from the content presented in Appendix E are in draft stage, which are to be submitted soon for publication.

Moreover, ethics review of the survey on the use of IT in infrastructure management was conducted as part of this research work. The Behavioral Research Ethics Board reviewed and approved the IT survey questionnaire (attached at Appendix C) and all associated documents. A certificate of approval was issued on Aug 27, 2011, reference number, UBC BREB # H10-00050. The certificate was subsequently renewed for two years—the period of the survey, which was terminated on Aug 08, 2013.

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List of Abbreviations

-	Partially Satisfied
+	Fully Satisfied
√	Compliance
3D	Three Dimension
AADT	Average Annual Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ABS	Acrylonitrile Butadiene Styrene
AC	Asbestos Cement
Actor-Onto	Actor Ontology
AEC	Architecture, Engineering, Construction
AEC/FM	Architecture, Engineering, Construction and Facilities Management
agcXML	Associated General Contractors of America Extensible Markup Language
AI&CAR/TCA Reporting	Asset Inventory and Condition Assessment Reporting/Tangible Capital Asset Reporting
AIIS	Asset Information Integrator System
AMMP-WF	Asset Maintenance Management Planning Work Function
ANOVA	Analysis of Variance
Arc-GIS	Arc Geographic Information System
ASCE	American Society of Civil Engineers
As-is TM	As-is Transaction Map
Asp.net	Active Server Pages are an Integral Part of .Net Framework
BC	British Columbia
BIM	Building Information Model
BPMM	Business Process Maturity Model
BPSS	Business Process Specification Schema
C2C	Computer-to-Computer
CA	Corrugated Aluminium
CAD	Computer Aided Drafting/Computer Aided Design
CEDAC	Cause and Effect Diagram with the Addition of Cards
CFMA	Construction Financial Management Association
CI	Cast Iron
CIB W78-W102	Conseil International du Batiment pour la Recherche l'Etude et la Documentation" or in English "International Council for Research and Innovation in Building and Construction
CM	Construction Manager
CMMI	Capability Maturity Model Integration

COINS-BIM	Construction Objects and the Integration of Processes and Systems–Building Information Model
COINS-CEM	Construction Objects and the Integration of Processes and Systems–Construction Engineering Method
CPVC	Chlorinated Polyvinyl Chloride
CQs	Competency Questions
CS	Concrete Cement
CSC-MM	Construction Supply Chain Maturity Model
DE	Design Engineer
DI	Ductile Iron
DRIVE	Define, Review, Identify, Verify, and Execute
dTIM	Deighton Total Infrastructure Management System
ebXML	electronic business Extensible Markup Language
eCPPM	European Conference on Product and Process Modeling
Eds.	Edition
EFQM/BQM	European Foundation for Quality Management/Business Quality Model
E-mail	Electronic Mail
F	Full Compliance
FAA-iCMM	Federal Aviation Administration-Integrated Capability Maturity Model
FC	Full Compliance
FIATECH	Fully Integrated and Automated Technology
FIPS	Federal Information Processing Standard
FTEs	Full Time Employees
FTP	File Transfer Protocol
GC	General Contractor
GHz	Giga Hertz
GI	Galvanized Iron
GS	Galvanized Steel
H	High
HDPE	High Density Polyethylene
IAI	International Alliance of Interoperability
IC-Pro-Onto	Infrastructure and Construction Process Ontology
ICT	Information and Communication Technology
ID	Idenitfy
IDEF0	Integration Definition Function Modeling Technique
IDM	Information Delivery Manual
IFC	Industry Foundation Class

IIS	Internal Information Server
IMM	Interactive Capability Maturity Model
IM-PMM	Infrastructure Management - Process Maturity Model
IPD-Onto	Infrastructure Product Ontology
ISEC	International Structural Engineering and Construction Conference
IT	Information Technology
ITC	Information Technology in Construction
ITMP	Infrastructure Transaction Management Portal
IU-BIM	Indiana University Building Information Modeling
IU-BIM-PM	Indiana University Building Information Modeling Proficiency Matrix
JIIRP	Joint Infrastructure Interdependency Research Program IT
M	Medium
MM	Maturity Model
MS	Microsoft
MSP	Managing Successful Programs Methodology
MT	Message Template
MVD	Model View Definition
N	Non or Not at All Easy or Not Applicable
N	Non Compliance
N/A	Not Applicable
NBIMS	National Building Information Model Standards
NC	Non Compliance
NIBS	National Institute of Building Sciences
NSERC	Canadian Natural Sciences and Engineering Research Council
Open-edi Onto	Open-electronic Data Interchange Ontology
OPM3	Organizational Project Management Maturity Model
OPT	Optional
OS	Operating System
OWL	Ontology Web Language
P	Partial Compliance
P2C	Person-to-Computer
P2P	Person-to-Person
P3M3	Portfolio, Program, and Project Management Maturity Model
PC	Partial Compliance
PDF	Portable Document Format
PE	Polyethylene
PMBOK	Project Management Body of Knowledge

PMI	Project Management Institute
PP	Polypropylene
PSAB	Public Sector Accounting Board
PVC	Polyvinyl Chloride
RAM	Random Access Memory
RDF	Resource Description Framework
RDF-S	Resource Description Framework Schema
REA	Resource-Event-Agent
REQ	Required
RIVA	Real Time Infrastructure Valuation Analysis
RPM	Reinforced Plastic Mortar
S	Steel
SC	Subcontractor
SEI	Software Engineering Institute
SPICE	Standardized Process Improvement for Construction Enterprises
SPICE3	Semantic Collaborative Portal for the Exchange of Infrastructure Interdependencies Information
SQL	Structured Query Language
SORP	Statement of Recommended Practice
SWOT	Strengths, Weaknesses, Opportunities, and Threats
TCA	Tangible Capital Asset
TCA_Extended_Onto	Tangible Capital Asset Extended Ontology
TCA_Kernel_Onto	Tangible Capital Asset Kernel Ontology
TCA_Onto	Tangible Capital Asset Ontolgoy
TFP	Transaction Formalism Protocol
TM	Transaction Map
To-be TM	To-be Transaction Map
Trans_Dom_Extended_Onto	Transaction Domain Extended Ontology
Trans_Dom_Kernel_Onto	Transaction Domain Kernel Ontology
Trans_Dom_Onto	Transaction Domain Ontology
Trans_Upper_Onto	Transaction Upper Ontology
UBC	University of British Columbia
UK	United Kingdom
UML	Unified Modeling Language
UMM	UN/CEFACT Modeling Methodology
UN/CEFACT	United Nation's Center for Trade Facilitation and Electronic Business
URL	Univeral Resource Locator

USA	United States of America
VC	Vitrified Clay
VISI	Voorwaarden Scheppen VoorInvoering Standaardisatie
VWI	Visio Workflow Interchange
X	Non Compliance/Not applicable
X	Non Satisfied
XML	Extensible Markup Language

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Chapter 1 Introduction

1.1 Introduction

This chapter[1] is a brief overview of the complete research work that relates to transaction formalization in infrastructure management. Presently, communications (i.e. transactions) between the infrastructure agencies are accomplished in a manual and *ad hoc* basis. The growing trend is to transform these manual communications to a more formalized computer-based communications, which is the core focus of this research work. There are three main research questions "what transactions are candidates to formalize?" "why formalize transactions?" and "how to formalize and manage transactions?" Answers to these questions were explored through setting up four main research objectives that were decomposed into nine sub-objectives. The four main objectives are: benchmark initiatives, build ontologies, develop protocol, and apply the protocol. This chapter is divided into six sections. Discussion in different sections of this chapter is organized according to four research objectives. This chapter; introduces the research topic and states the problem, discusses research objectives, framework, scope and contributions, briefly reviews literature, discuss the case study, and describes thesis organization.

1.2 Problem Statement and Solutions

Infrastructure agencies have the prime responsibility to deliver services (e.g. road access, water supply, sewage disposal, and so on) to users in an effective and efficient manner through a complex and interdependent network of infrastructure systems. Various private, para-governmental (crown corporations), and public agencies (e.g. municipal, regional, provincial, and federal governments) own, operate, and manage these infrastructure systems using a wide range of information systems, each based on different proprietary data models. Different agencies interact with each other and exchange infrastructure information to accomplish a wide range of collaborative tasks. As infrastructure agencies increasingly rely on computer-based systems to manage infrastructure data, much of the information that was traditionally exchanged through human-to-human communications can now be exchanged electronically through computer-to-computer data exchange. This allows for more extensive, rapid, and error-free exchange of information,

[1] A version of the chapter is published in the 9th European Conference on Product and Process Modeling (eCPPM 2012).

Zeb, J.; Froese, T.; and Vanier, D. (2012). "A Review of the Process Formalization Standards to Develop a Transaction Protocol for Infrastructure Management", Gudnason & Scherer (Eds.), eWork and eBusiness in Architecture, Engineering and Construction, © 2012 Taylor & Francis Group, 9th European Conference on Product and Process Modeling (eCPPM 2012), July 25-27, 2012, Reykjavik, Iceland. The main focus of this paper is to review state-of-the-art work process and communication formalization standards and methodologies in various industries and build on the existing standards to develop the proposed Transaction Formalism Protocol as part of this research work.

but it requires more formal specifications and agreements to govern these data exchanges. The terms; data exchange, information exchange, communication, communication process, and transaction are used interchangeably in this research work. A transaction is defined "as any communication or interaction between the sender and receiver roles that make up the information flow through a single or collection of a sequenced set of messages" (Zeb and Froese, 2012). Examples of transactions between infrastructure organizations or between infrastructure management systems include: communications during a disaster response ("is power available in this area?" "who is responsible for this section of roadway?" "when will water to be restored to this area?"); coordination between buried utility agencies to provide a "call-before-you-dig" call center for excavations; or aggregation of data from multiple infrastructure management software for the purpose of performing sustainability analysis or asset inventory and condition assessment reporting to meet public sector accounting requirements. In addition, formalized transactions can be used in the multi-agency situational awareness system wherein the provincial government requires information from many other organizations outside the provincial jurisdiction to prepare for and mitigate the impacts of emergency incidents through timely sharing of geospatially-referenced information. The system provides situational awareness data aggregation and automate the information dissemination and communication process during an emergency and allows visual representation of this information on maps (Stewart, 2010).

Currently, work processes and data exchanges between collaborating partners in the Architecture, Engineering, Construction, and Facilities Management (AEC/FM) industry are manual (human-to-human), unstructured, and *ad hoc*: which all result in poor communication. Some of the disadvantages of this poor communication are time and cost overruns, productivity losses, rework, and reduced quality. Emerging trends in the AEC/FM industry for globalization and partnering along with enhanced pressure to reduce project time and cost require information to be exchanged in an effective way (Pouria *et al.* 2002). "Some industry studies have estimated that 30% of design and construction costs, excluding hard-dollar (i.e. bricks and mortar) materials costs, are wasted due to poor communication and inefficiencies within and between companies" (Unger 2005, p. 1). The results of the FMI/CMAA 4th and 5th annual surveys of owners indicated that poor communication is the main cause of the lack of collaboration and coordination between various partners (FMI/CMAA, 2003 and 2004). The Voorwaarden Scheppen VoorInvoering Standaardisatie (VISI) organization studied large-scale infrastructure projects and found that the lack of structured communication was one of the main bottlenecks in implementing infrastructure projects (VISI, 2007). To overcome all of these problems, there is a need to have a paradigm shift of the current practices of manual communication to a more formalized computer-to-computer based exchange of information between different partners of the AEC/FM industry. One possible solution is shown in Figure 1-1.

For computer-based communications, the data exchanges in Figure 1-1 between the parties require more formal descriptions of the flow (Transaction Map, TM) and structure of information (Message Template, MT). The complete documentation of the formal descriptions, including the formalized TM and MTs, are referred to as *transaction specifications or standard transaction agreements,* as illustrated in Figure 1-1. Although the inevitable trend in communications technology is towards increasing computerization, computer-to-computer data exchange, and, therefore, transaction formalization, there are many challenges that prevent this formalization from being an easy or efficient process. These challenges include the issues of identifying the spectrum of transactions that exist within the infrastructure industry; assessing transactions to determine those that are best suited for formalization; and developing an appropriate process for carrying out this formalization. At the level of the data structures needed to construct transaction specifications, the diversity of software used within the infrastructure industry has led to significant challenges with heterogeneity in data forms, data (class) definitions, and data aggregation structures (Felio, 2012). These issues can be grouped to create the three main research questions of the thesis:

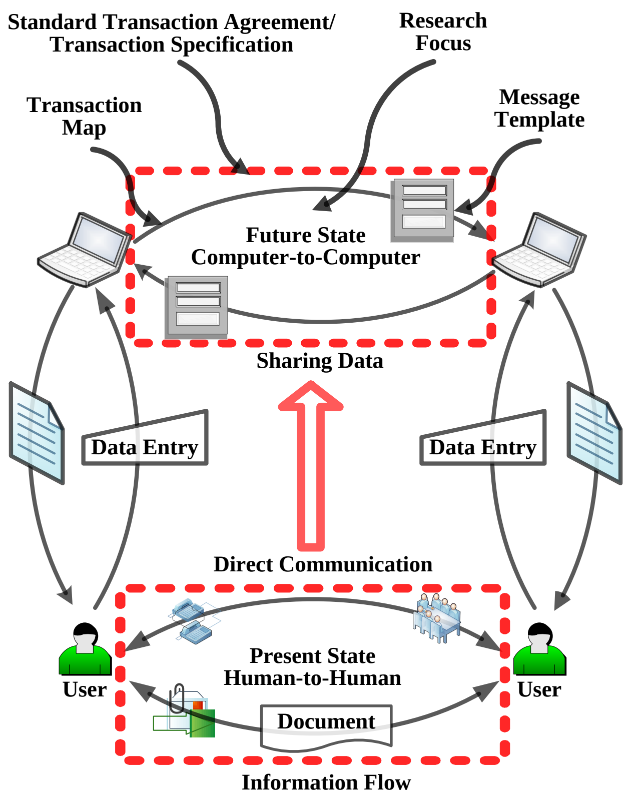

Figure 1-1 Research focus

i. *What transactions are candidates to formalize?* The first question pertains to identifying the transactions that have the greatest potential for IT improvement. This issue was addressed by conducting an information technology (IT) survey in the domain of infrastructure of the AEC/FM industry.

ii. *Why formalize transactions?* Or *how to assess transaction formalization*? The second question pertains to the transaction formalization assessment. This issue was addressed through the development and application of an Infrastructure Management-Process Maturity Model (IM-PMM) to assess the degree to which work processes and communications/transactions are formalized in the domain of infrastructure management.

iii. *How to formalize and manage transactions?* The third question addresses transaction and data formalization in term of developing and applying transaction specifications. These issues were addressed through developing and applying an ontology-supported Transaction Formalism Protocol (TFP) in the domain of infrastructure management. The TFP is a procedure developed to formalize transactions and create transaction specifications effectively and efficiently. To support the development and application of the TFP, two ontologies were built: the Transaction Domain Ontology (Trans_Dom_Onto), and the Tangible Capital Asset Ontology (TCA_Onto). According to Gruber (1995), an ontology is a "formal, explicit specification of a shared conceptualization." The two ontologies represent a shared understanding of how things exist in the real world; they provide consistent semantics and explicit definitions of the terms in a domain. The Trans_Dom_Onto represents transaction related knowledge to support the design, management, and implementation of transactions or transaction maps and development of the TFP. The TCA_Onto represents the Tangible Capital Assets (TCAs) to support the design of MTs in a consistent and neutral data format to address message-based interoperability between information systems of the infrastructure organizations. The TCA_Onto was developed as an extension to the Infrastructure Product Ontology, IPD-Onto (Osman, 2007). According to PSAB (2009), the TCAs are "non-financial assets having physical substance that are acquired, constructed, or developed and: are held for use in the production or supply of goods and services; have useful lives extending beyond an accounting period; are intended to be used on a continuing basis, and are not intended for sale in the ordinary course of operations."

The proposed TFP protocol is an eight-step procedure was developed from two different perspectives. The *TFP Specification* was developed from a conceptual perspective where each step of the protocol was modeled as a distinct function for which inputs, controls, mechanisms, tools/techniques, and outputs were defined. On the other hand, the *TFP Tool* is comprised of a set of Excel-based forms and guidance developed for specific steps of the protocol (i.e. forms were developed for some steps of the protocol, whereas for others, only guidance was provided on how to accomplish a specific step). The transaction development personnel will use the proposed protocol to develop transaction specifications. Related to the development of formalized transactions is the issue of managing a collection of transaction specifications. This was explored through the development of an Infrastructure Transaction Management Portal (ITMP).

The proposed TFP protocol was applied to develop transaction specifications for the Asset Inventory (PSAB, 2008) and Condition Assessment (SORP, 2008) Reporting/Tangible Capital Asset (AI&CAR/TCA) Reporting process that was identified through an IT survey conducted as part of this research work. The formalized transaction specification was implemented in a prototype Asset Information Integrator System (AIIS). The prototype system collects, stores, visualizes, and analyzes the asset inventory and condition assessment information received from different municipalities to help the provincial government to: understand long-term financial needs of municipalities for infrastructure management; develop a consistent and planned approach for funds allocation; and present the case to the federal government for additional funding, if required.

1.3 Objectives, Framework, Scope, and Contributions

1.3.1 Research Objectives

Based on the aforementioned three research questions, the research in this dissertation is organized into four core objectives: (1) benchmarking relevant IT initiatives, (2) building the supporting ontologies, (3) developing a protocol for formalizing transactions, and (4) applying the protocol. These objectives involve several main sub-objectives, illustrated in Figure 1-2:

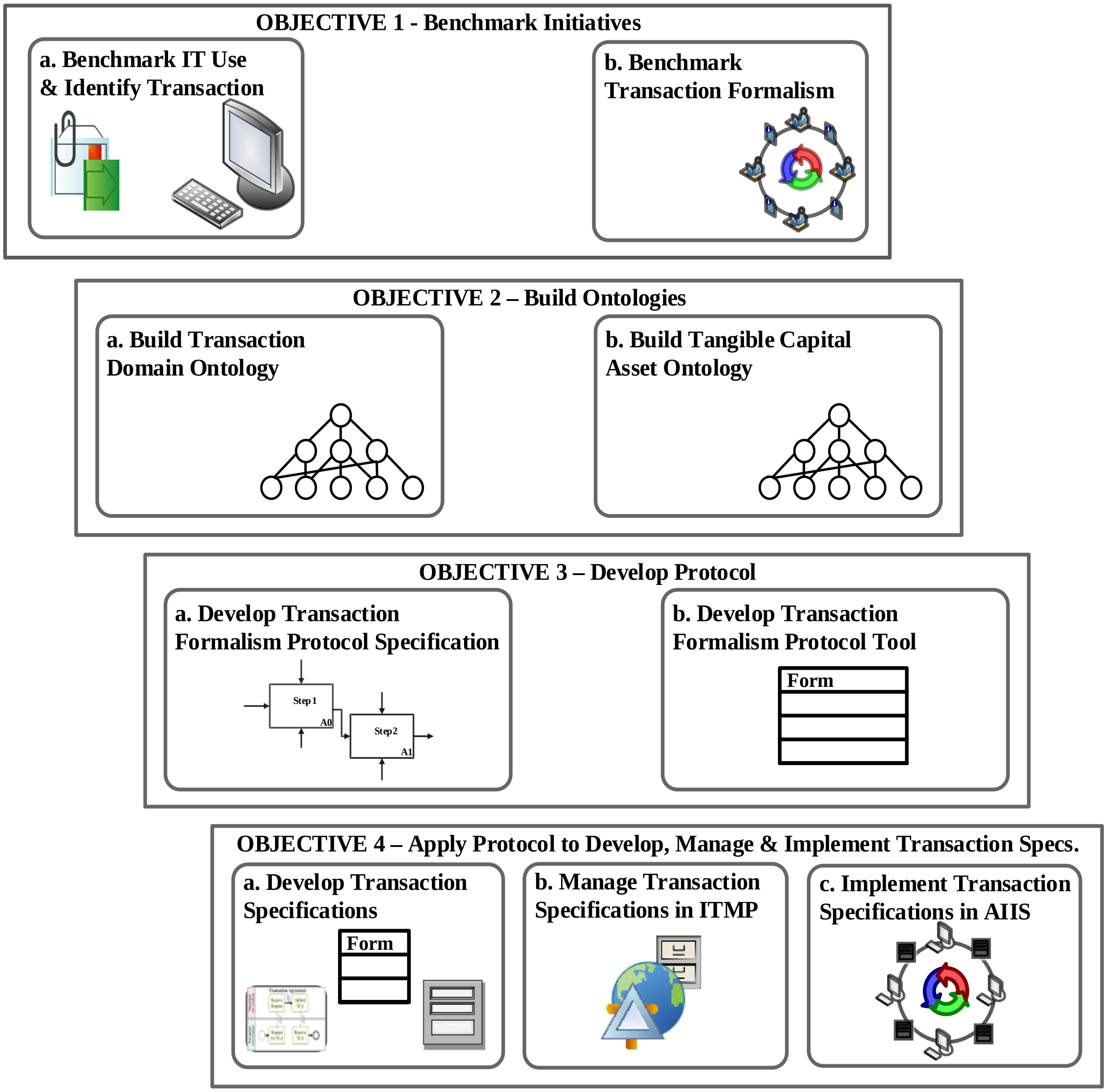

Figure 1-2 Abstract research framework

- *Objective 1—Benchmark initiatives:* The first objective is to survey the current use of IT in municipal infrastructure management and to develop an approach for assessing infrastructure transaction processes. The sub-objectives are as follows:
    - Benchmark IT use in municipal infrastructure management to identify the range of IT systems used in the infrastructure industry, the communication channels used to exchange information between the parties, and the information transactions that offer the greatest potential for IT improvements.
    - Benchmark transaction formalism in the domain of infrastructure management by developing and applying the IM-PMM to assess the degree to which work processes and communications are formalized in the domain of infrastructure management.

- *Objective 2—Build ontologies to support transaction design, management, and implementation:* Prior to developing the TFP in Objective 3, the relevant ontologies were required, and these are the focus of Objective 2 and the following sub-objectives:
  - Build a Trans_Dom_Onto to support the design, management, and implementation of transaction specifications (i.e TMs+MTs+transaction specification documentation) in the domain of infrastructure management and development of the TFP.
  - Build a TCA_Onto as an extension to the IPD-Onto to support the design of MTs for the proposed area of application, i.e. AI&CAR/TCA Reporting.
- *Objective 3—Develop a protocol to formalize transactions:* The third objective is to develop a step-by-step procedure—the proposed TFP, which is an eight-step procedure devised to formalize transactions in the domain of infrastructure management. The proposed TFP was developed at two levels of abstraction: the TFP Specification and the TFP Tool. The sub-objectives are as follows:
  - Develop the TFP Specification that specifies the inputs, controls (constraints), mechanisms, tools/techniques, and outputs for each step of the protocol.
  - Develop the TFP Tool as a set of forms and guidance that the transaction development will use to define transaction specifications in the domain of infrastructure management.
- *Objective 4—Apply the protocol to develop, manage (i.e. archive), and implement transaction specifications:* The fourth objective is to apply the proposed ontology-supported TFP. The protocol was applied in the domain of infrastructure management to formalize the AI&CAR/TCA Reporting process (transaction specification) that was implemented in the prototype AIIS. Three sub-objectives were identified as follows:
  - Develop a transaction specification for the application area—AI&CAR/TCA Reporting, the TFP.
  - Develop a prototype ITMP to manage (archive) transaction specifications as part of the transaction specification management.
  - Demonstrate and test/evaluate the proposed approach through developing the prototype AIIS that implements the AI&CAR/TCA Reporting transaction specification.

1.3.2 Research Framework

The high-level framework devised for this research work is shown in Figure 1-2 above. The research framework was developed based on the four core objectives set-forth in this research work. A more detailed framework was also developed that describes the methodology, requisite tools/techniques, deliverables, and evaluation techniques for each objective as shown in Figure 1-3 to Figure 1-6. A brief description of each of these components of each objective as follows (with more detailed description presented in the relevant manuscript-based chapters). The *methodology* describes the step-wise procedure devised to accomplish an objective. The *requisite tools/techniques* refers to the developmental tasks, approaches, or software application that are used to achieve a specific objective and *deliverables* are the output products developed during this research work. The *evaluation techniques* are the methods used to verify and validate the authenticity and accuracy of the deliverables.

1.3.2.1 Framework for Objective 1, Benchmark Initiatives

The detailed framework for Objective 1 is shown in Figure 1-3. For each sub-objective, a set of tools/techniques, deliverables, and evaluation techniques that were developed specifically for the research are identified.

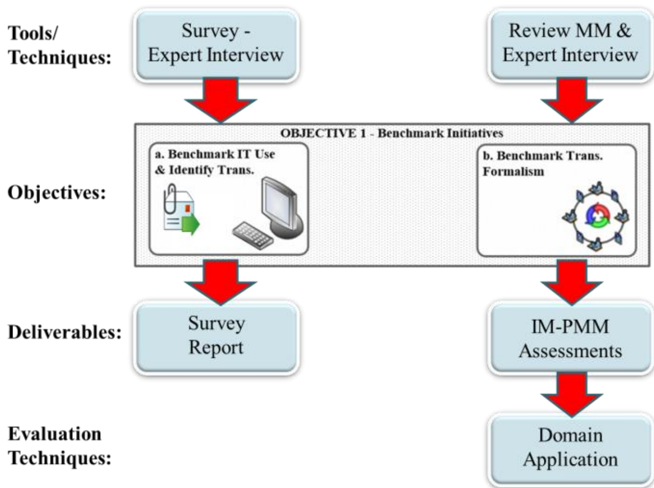

Figure 1-3 Detailed framework for objective 1

a. Benchmark IT Use and Identify Transaction for IT Improvement

Tools/techniques and deliverables—an expert interview survey technique was used. Infrastructure management experts from different municipalities were interviewed in structured face-to-face interviews. The deliverable, presented in Chapter 2, is a detailed survey report describing the use of IT in municipal infrastructure management and a set of typical transactions that have the greatest potential for IT improvement.

Methodology—the IT survey was conducted using a five-phase approach: planning, design, execution, analysis, and reporting as discussed in Chapter 2, Section 2.2.

b. Benchmark Transaction Formalism

Tools/techniques and deliverables—two techniques were used: a review of existing maturity models and expert interviews. Relevant existing maturity models were reviewed as part of the literature review and shortcoming were identified that led to the development of the proposed IM-PMM, which was applied in the area of infrastructure management. The two deliverables (see Chapter 3) are the proposed IM-PMM and a set of assessments describing the degree to which work processes and transactions are formalized in the domain of infrastructure management.

Evaluation techniques—the proposed IM-PMM was evaluated through domain application. The proposed maturity model was applied in the domain of infrastructure management to verify that it is applicable in the practical context. The content of the proposed IM-PMM was validated through industry experts.

Methodology—a five-step methodology was devised in line with the procedure developed by Becker and Knackstedt (2009) for developing maturity models. (i) *Define the problem*—the problem was explicitly defined through needs assessment. (ii) *Compare existing maturity models*—a set of relevant existing maturity models was compared to assess gaps. (iii) *Develop the IM-PMM*—the proposed model was developed based on the review of the existing maturity models. (iv) *Apply the IM-PMM*—the IM-PMM was applied to test its' applicability in the domain of infrastructure management. (v) *Evaluate the IM-PMM*—this step relates to evaluating the proposed IM-PMM.

1.3.2.2 Framework for Objective 2, Build Ontologies

The detailed framework devised for Objective 2 is presented in Figure 1-4. The research components were similar for both sub-objectives (sub-objectives (a) the construction of the Trans_Dom_Onto and (b) the creation of the TCA_Onto):

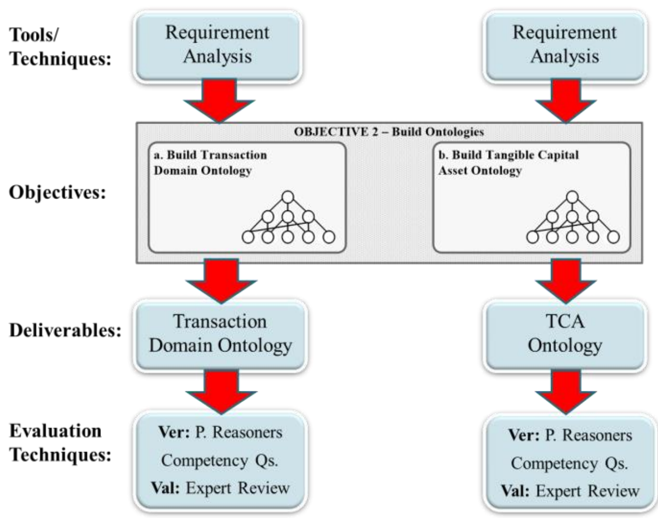

Figure 1-4 Detailed framework for objective 2

Tools/techniques and deliverables—a requirement analysis technique was used to carry out needs assessment for the development of both the ontologies. To capture requirements, an extensive literature review of the state-of-the-art standards, ontologies, and information models was carried out to reach an understanding on how others have modeled various aspects of the transactions (Trans_Dom_Onto) and tangible capital assets (TCA_Onto). According to Gruninger and Fox (1995), these requirements guide the formulation of the competency questions, which the ontology should be able to answer. Based on the requirement analysis, a set of competency questions was developed for both the ontologies. The creation of the Trans_Dom_Onto and TCA_Onto are the two main deliverables of Objective 2, which are discussed in detail in Chapter 4 and Chapter 5 respectively. The Trans_Dom_Onto representing transaction domain knowledge to support the design, implementation, and management of transactions in the domain of infrastructure management and the TCA_Onto representing the TCA knowledge to support the design of MTs defined for AI&CAR/TCA Reporting.

Evaluation techniques—according to Gomez-Perez *et al.* (2003) and Gomez-Perez (1996 and 2001), ontology evaluation is the process of judging the content of the ontology with respect to some frame of reference, such as a set of requirements, competency questions (defined as ontology verification) and the real world model of the domain of interest (defined as ontology validation). In ontology verification, the knowledge representation is judged to ensure that the model is implemented correctly; whereas ontology validation ensures that a correct model is implemented from the real world perspective. In this research work, Protégé (Protégé, 2014) automated reasoners and competency questions were used for ontology verification; whereas expert review approach was used for ontology validation.

Methodology—a ten-step methodology was devised to build the Trans_Dom_Onto, which was a hybrid version of the various approaches developed by Fernandez-Lopez *et al.* (1997); Uschold and Gruininger (1996); and Noy and McGuinness (2001). These ten steps are: (i) define ontology coverage; (ii) capture competency questions; (iii) generate/create taxonomy; (iv) reuse existing ontologies; (v) develop Transaction Domain Kernel Ontology, (Trans_Dom_Kernel_Onto); (vi) extend Trans_Dom_Kernel_Onto to develop Transaction Domain Extended Ontology (Trans_Dom_Extended_Onto); (vii) capture ontology; (viii) code ontology; (ix) evaluate ontology; and (x) document ontology. These steps are explained in Chapter 4. A similar methodology was used for the TCA_Onto, with the addition of a preliminary step to identify motivating scenarios is presented in Chapter 5.

1.3.2.3 Framework for Objective 3, Develop Transaction Formalism Protocol

Figure 1-5 depicts the tools/techniques, deliverables, and evaluation techniques used to accomplish Objective 3, the development of the TFP and the two sub-objectives, the development of the TFP Specification and its implementation in the TFP Tool.

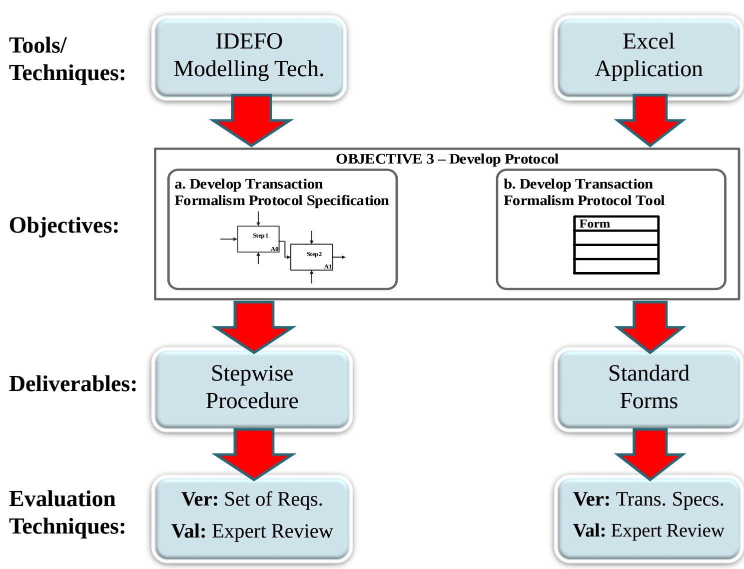

Figure 1-5 Detailed framework for objective 3

a. Transaction Formalism Protocol Specification

Tools/techniques and deliverables—the Integration Definition Function Modeling Technique, IDEF0 (NIST, 1993) was used to develop the TFP Specification. This technique treats each step of the TFP protocol as a distinct function, and for each, the inputs, controls, mechanisms, tools/techniques, and outputs were specified. According to NIST (1993), the IDEF0 has several benefits that include comprehensiveness, ease of use, consistency, time-tested approach, and software support. The deliverable of the TFP Specification is an eight-step functional model describing the procedure in terms of inputs, controls, mechanisms, tools/techniques, and outputs.

Evaluation techniques—the evaluation of the TFP Specification included its implementation and application in the form of the TFP Tool. Also, the proposed TFP Tool was verified against a set of quality criteria.

Methodology—the proposed TFP Tool was developed using a rapid prototyping methodology—a four-step methodology devised based on the approach formulated by Adesola and Baines (2005) for the development of business process improvement methodologies. The approach involves reviewing and analyzing current frameworks/methodologies and then selecting the relevant candidates based on the key selection criteria. These steps include: (i) select the candidate standards, (ii) benchmark existing standards, (iii) link and build on existing standards, and (iv) develop the proposed TFP.

b. Transaction Formalism Protocol Tool

Tools/techniques and deliverables—for the development of the TFP Tool, Microsoft Excel was used as an application development platform because of low cost, ease of use, and easy availability. The deliverable of the TFP Tool is a set of forms and guidance that the transaction development personnel can use to formalize transactions in the domain of infrastructure management.

Evaluation techniques—the TFP Tool was verified by applying it in the domain of infrastructure management to create transaction specifications for the AI&CAR/TCA Reporting; and it was validated through an expert review using a criteria based approach.

Methodology—the TFP Tool was developed using a rapid prototyping methodology, where the structure of the application (and therefore the development steps) directly mirrored the steps of the TFP Specification.

1.3.2.4 Framework for Objective 4, Apply the Protocol to Develop, Manage (Archive), and Implement Transaction Specification

Figure 1-6 illustrates the detailed research framework for Objective 4, the application of the TFP, and its three sub-objectives, the creating of a transaction specification for the AI&CAR/TCA Reporting, the demonstration of an illustrative platform for managing collections of transaction specifications (the ITMP), and the implementation of the specification within an illustrative transaction platform (the AIIS).

a. Develop Transaction Specifications

Tools/techniques and deliverables—the transaction specification for the application area of the AI&CAR/TCA Reporting was developed using a combination of the TFP Tool and software applications. This transaction specification was developed in an MS Excel based tool. As part of the specification, the TM was developed using the Unified Modeling Language (UML), and the MTs were designed in Microsoft InfoPath Designer. These applications were selected due to ease of use and availability. The deliverables are a set of forms completed with the required information, To-be TM, and MTs defined for the AI&CAR/TCA Reporting, which are discussed in detail in Appendix K.

Evaluation techniques—the expert review technique was used to evaluate the transaction specification developed for the AI&CAR/TCA Reporting. The transaction specification was refined accordingly, incorporating modification proposed during the expert review.

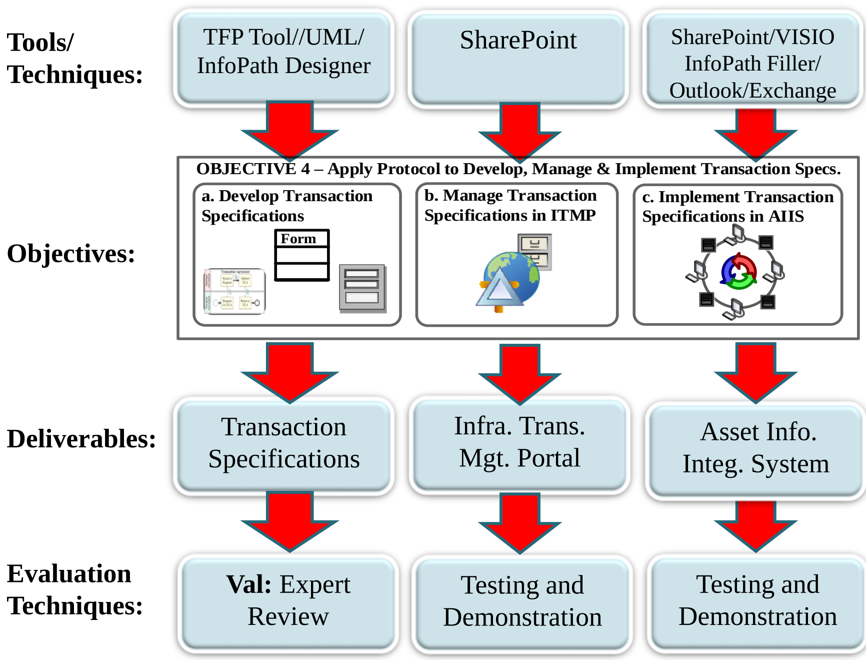

Figure 1-6 Detailed framework for objective 4

b. Develop Infrastructure Transaction Management Portal

Tools/techniques and deliverables—the prototype ITMP is a website that stores and archives the transaction specifications for future use. The ITMP was developed in MS Sharepoint. A fully operational ITMP was the sole deliverable of this sub-objective that is discussed in Chapter 8.

Evaluation techniques—the prototype ITMP was evaluated through testing to demonstrate that the transaction specification developed for the AI&CAR/TCA Reporting was successfully managed or archived in the portal.

Methodology—the prototype ITMP was developed using a four 4C approach: create a virtual directory, create collection site, create subsets, and create web pages. The details are given in Chapter 8.

c. Develop Asset Information Integrator System

Tools/techniques and deliverables—the transaction specification developed for the AI&CAR/TCA Reporting was implemented through developing the prototype AIIS using the MS SharePoint, Sharepoint Designer, and MS

VISIO Premium. In this system, the information between the provincial and municipal government was exchanged though the AIIS using a set of applications; InfoPath Filler, Outlook, and MS Exchange. These applications were selected due to availability, ease of use, and code-free development of the AIIS system. The deliverable is a prototype AIIS that collects, stores, compares, and analyzes the AI&CAR/TCA information received from various municipalities. The development and application of the proposed AIIS system are explained in Chapter 9.

Evaluation techniques—the AIIS system was evaluated through testing to demonstrate that the AI&CAR/TCA information was exchanged between the parties successfully.

Methodology—the prototype AIIS was developed using a four step approach: create website and library, review and modify the defined MTs, design and configure workflows, and add functionalities in the AIIS system. The methodology is discussed in detail in Chapter 9.

1.3.3 Research Scope

The scope of this research is organized according to the four research objectives.

1.3.3.1 Scope of Objective 1, Benchmarking Initiatives

Benchmark IT use—the use of IT in the domain of municipal infrastructure management was benchmarked through conducting a structured face-to-face interview. The population for the survey was the set of municipalities in the Southwestern British Columbia, Canada (within a practical and economic travelling distance for the researchers to carry out face-to-face interviews). The respondents were selected to be experts from local and regional governments (municipalities, in the province of British Columbia). With respect to the IT component, the scope focussed on general IT use for work processes such as financial management, accounting, human resource management, procurement, work order management, environmental management, progress tracking, and property information management. In terms of infrastructure systems, the scope was chosen to be water, wastewater and transportation systems. Finally, the scope was further constrained to the work functions related to one of the components of municipal infrastructure management, namely asset management.

Benchmark transaction formalism—the proposed IM-PMM was developed to benchmark the degree to which work process and communications were defined in the domain of infrastructure management. The proposed IM-PMM was developed from the process design perspective and not from the process operation or management perspective. The five-stages and elements of the proposed IM-PMM were developed, as discussed in Chapter 3, based on the intention that it will be applied in the area of infrastructure management: however, owing to the generic definitions of these stages and the elements, the researcher is confident that it can be applied in other areas or industries. The generality of the proposed IM-PMM, however, has not been tested.

1.3.3.2 Scope of Objective 2, Build Ontologies

As part of this research work, two ontologies were built: the Trans_Dom_Onto, and the TCA_Onto. As the name implies, the transaction ontology represents transaction knowledge to support the design, implementation, and management of transaction specifications in the domain of infrastructure management. On the other hand, the

TCA_Onto represents TCA knowledge in the facility and infrastructure sectors with specific focus on transportation, bridges, water, wastewater, and solid waste management. The TCA_Onto supports the design of MTs to report the AI&CAR/TCA information.

1.3.3.3 Scope of Objective 3, Develop Transaction Formalism Protocol

From the development perspective, the TFP Specification was developed as a step-wise procedure incorporating the important steps that are required over the life cycle of a transaction specification. The protocol is communication centric rather than work process centric. From the application perspective, the TFP Tool was developed to be applicable in the domain of infrastructure management.

1.3.3.4 Scope of Objective 4, Apply the Protocol to Develop, Manage, and Implementation Transaction Specifications

The target of this component of the research was to develop, manage, and implement the transaction specification for the AI&CAR/TCA Reporting. The transaction specification development scope was targeted towards developing specifications for the AI&CAR/TCA Reporting. The transaction specification archival scope encompasses the development of a portal as part of the transaction management. The ITMP was developed to archive transaction specification developed in the domain of infrastructure management. The portal can be extended easily when more transaction specifications are developed in other areas of application or industries. The scope of the transaction specification implementation includes the development of a web-based collaboration system—the AIIS. This prototype system implements the AI&CAR/TCA Reporting transaction. This system was designed to exchange the AI&CAR/TCA information between the provincial and municipal governments. In addition, the AIIS was provided with basic functionalities to collect, store, visualize, and analyze reports received from different municipalities.

1.3.4 Brief Description of Research Contributions

The objective-wise contributions of this research work in terms of major, medium, and minor contributions are presented here; however, a detailed discussion is given in Chapter 10.

- Objective 1—Benchmark initiatives
  - The survey of IT use in infrastructure management explored a niche segment of the AEC/FM industry that has seldom been studied, which is a medium contribution of this research work.
  - The development of the IM-PMM is a medium contribution to the body of knowledge as none of the existing maturity models fulfill the requirements of this research, which focuses on the way work processes and communications are designed rather these are operated and managed.
- Objective 2—Build ontologies
  - The development of the Trans_Dom_Onto is a major contribution of this research work that represents the transaction domain knowledge in the area of infrastructure management.

    - To support the design of message templates in the area of infrastructure management, a TCA_Onto was developed to represent the TCAs in the transportation, water, wastewater, and solid waste sectors, which the researcher believes to be a major contribution to the body of knowledge.
- Objective 3—Develop the protocol
    - The development of the proposed TFP Specification and TFP Tool are two major contributions of this research work that the transaction development personnel will use to define transactions effectively and efficiently.
- Objective 4—Develop, manage, and implement transaction specifications
    - Another minor contribution of this research work is the development of a transaction specification for the AI&CAR/TCA Reporting, which is an important communication in the area infrastructure management.
    - The researcher believes that the development of the ITMP for the management of transaction specifications for any future use in the domain of infrastructure is a medium contribution to the body of knowledge.
    - The development of the AIIS is also a medium contribution to the body of knowledge as the experts from different municipalities will use this system to exchange the TCAs effectively and efficiently.

1.4 Points of Departure

Several areas of knowledge provide the foundations upon which this research is built. The literature pertaining to the following primary points of departure is briefly summarized here and discussed more fully in subsequent chapters: IT surveys (Chapter 2), maturity models (Chapter 3), ontology development (Chapter 4 and Chapter 5), and the state-of-the-art standards and methodologies (Chapter 6 and Chapter 7).

1.4.1 A Review of Surveys on the Use of IT

1.4.1.1 Global Context

In the past decade, several international surveys have been carried out to benchmark IT usage in the AEC/FM industry. The Nordic IT Barometer series is a longitudinal survey conducted in the Nordic (Sweden, Denmark, and Finland) construction industry at different times (Howard and Samuelson, 1998; Samuelson, 2002; and Samuelson, 2008). It compares the results and benchmark IT usage in the three core areas: projects webs, computer aided design (CAD), and electronic trade. It also provides information about communication tools and the current access to computers. It also provides a future road map of IT in the Nordic construction industry.

A similar IT survey has been conducted for the Singapore construction industry and its results are compared with the aforementioned Nordic IT Barometer series surveys. The focus of this survey was to check the general level of IT usage and specific adoption of IT originating from CORENET, an IT development program for the Singapore construction industry (Hua, 2005). A modified version of these Barometer surveys was conducted for the Jordanian AEC industry (El-Mashaleh, 2007). Moreover, computer usage was benchmarked for the New Zealand's building and construction industry (Dohert, 1997) and the state of internet use was surveyed in the Malaysian construction industry by (Mui *et al.* 2002).

The state of the IT in the Nigerian construction industry was explored to benchmark the level of adoption, its overall impact on the industry and barriers towards its adoption (Oladapo, 2007), while Scheer *et al.* (2007) investigated IT application experiences in the Brazilian AEC industry. In Turkey, one survey focused on the current and planned IT use for the acquisition of building product information on the supply (manufacturer & supplier) and demand side (architect), and identified methods and reasons for providing and receiving building product information (Tas and Irlayici, 2007). A subsequent Turkish survey was conducted with two different perspectives: industrial and academic. The industrial theme investigated the strategic role of IT implementations in the AEC industry and the academic theme explored the future road map for construction informatics, which encompasses the following areas: strategic IT management, integration, and interoperability of organizations and their information systems (Isikdag *et al.* 2009). Love *et al.* (2004) investigated IT investment in small and medium enterprises (SMEs) in the Australian Construction Industry, while Tse and Choy (2005) explored IT usage in the quantity surveying organizations of the Hong Kong construction industry.

The results of these surveys indicate that the construction industry is making use of standalone computer applications to undertake various construction processes. In summary, due to the propriety nature of the software applications used in the industry, there exists a problem of interoperability between these applications. Another common theme is that the use of internet is common for the exchange of information (information transactions) but this is largely limited to E-mail and downloading of documents posted on web sites. The surveys also indicate that transaction agreements in the construction supply-chain organizations are relatively formalized and electronic trade of building products is quite common. These studies have identified the road maps for construction IT implementation, but due to its fragmented nature, multiplicity of stakeholders, and short project durations, the results of the surveys indicate that the construction industry is still lagging behind other industries such as manufacturing, pharmaceutical, electronic, etc.

1.4.1.2 North American Context

Various surveys have investigated the state of IT and its impact on the North American construction industry. In the United States of America (USA), the Construction Financial Management Association (CFMA, 2008) conducts an IT survey for the construction industry every two years to benchmark systems, software, and solutions used by the construction organizations. Moreover, Issa *et al.* (2003) investigated the level of e-business implementation within the project management systems of the general contractors in the US Construction Industry.

In Canada, Rivard (2000) conducted a survey to assess the impact of information technology in the Canadian AEC industry. Rivard *et al.* (2004) investigated 11 case studies across Canada to define best practices in the use of IT in the AEC industry. At the University of Alberta, El-Ghandour and Al-Hussein (2004) have undertaken a survey to benchmark research published in 12 scientific journals between 1992 and 2001 in the field of IT. They have analyzed nine IT tools against 43 application areas. In addition, Froese and Han (2005) investigated the state of companies developing information technology for the construction industry in Canada.

The core thrust of these international and North American surveys was to investigate and identify the usage and impact of IT, barriers to its implementation and future direction of IT in the construction industry from the perspective of architectural, engineering, and contractor organizations. IT surveys from a local or municipal government perspective have rarely been conducted, specifically with regards to infrastructure asset management. The importance of this niche segment (municipal/local government) of the construction industry can better be judged through: (i) municipal or local government is managing 20% of the Canadian civil infrastructure portfolio valued at $5.5 trillion in 1999 constant dollars, (Vanier and Rahman, 2004), which is around $1.1 trillion; (ii) around 90% of the Canadian population is served by the municipalities; and (iii) as public organizations, municipalities have to ensure efficient utilization of the public money.

1.4.2 A Review of Maturity Models

A central component of this research is to develop a technique for assessing the degree to which work processes and communications are formally defined in the domain of infrastructure management. The following section reviews a set of relevant applications of maturity models in various related industries.

1.4.2.1 Maturity Models Related to Project Management in the Construction Industry

The Portfolio, Program, and Project Management Maturity Model, (P3M3) is a maturity model developed by the Office of Government Commerce (UK) and based on their Managing Successful Programs Methodology™ (MSP) standard (OGC-APM, 2010). The P3M3 model can be described as a five-stage maturity model. It is an advanced version of their Project Management Maturity Model. The focus of P3M3 is to provide effective guidance to organizations to establish process improvement initiatives at three: levels: portfolio, program, and project level.

The Organizational Project Management Maturity Model (OPM3) was developed by the Project Management Institute (PMI) and is based on the Project Management Body of Knowledge (PMBOK) standard (PMI, 2003). The focus of the OPM3 is to help organizations introduce best practices toward effective project management through understanding their project management processes, measuring the strengths and weaknesses of the processes, and suggesting improvements. It is used to evaluate the organization's overall portfolio, program, and project processes.

The Berkeley's Project Management Process Maturity Model is a five-stage model based on the PMBOK standard (Kwak and Ibbs, 2000). The purpose of the model is to benchmark (measure and compare) project management practices and processes in diversified organizations, including AEC/FM organizations. This model uses a systematic and incremental approach to benchmark project management practices in organizations. In addition, this model incorporates continuous improvement at the project level to address advances in the project management knowledge.

The Interactive Capability Maturity Model (ICMM) was developed by the National Institute of Building Sciences (NIBS), based on the National Building Information Model Standards, also known as NBIMS (McCuen and Suermann, 2007). This model helps organizations evaluate their project management practices and processes in relation to Building Information Model (BIM) implementation.

The Indiana University BIM Proficiency Matrix (IU-BIM-PM) was developed by their University Architect's Office and is based on the IU BIM standards (IU, 2009). The focus of the Proficiency Matrix is to evaluate and benchmark the maturity of the project management practices and processes in organizations in line with the use of BIM technologies and help guide them towards improvement in future BIM implementations.

The Construction Supply Chain Maturity Model (CSC-MM) is a four-stage model based on the Fully Integrated and Automated Technology (FIATECH) Road Map (Vaidyanathan and Howell, 2007). The CSC-MM framework helps construction supply-chain organizations to improve processes to achieve operational excellence.

The general summary of the existing initiatives related to maturity models in the construction domain is that: most use a five-stage model (i.e. infancy, preliminary, reactive, proactive, and integrated), most developments are attempting to improve the management of engineering in the field, and the development of maturity models is still an active research field related to the management of construction engineering projects.

1.4.2.2 Maturity Models Related to the Software Industry

The Capability Maturity Model Integration (CMMI), Version 1.3 and the Federal Aviation Administration-Integrated Capability Maturity Model (FAA-iCMM) are five-stage discrete models developed by the Software Engineering Institute (SEI, 2010). The CMMI is a process-improvement approach that helps organizations in the software industry to improve their processes through setting process improvement goals, providing guidance on how to achieve quality processes and benchmarking current processes. According to Ibrahim *et al.* (2001), the FAA-iCMM Version. 2 Framework guides organizations to improve their ongoing processes using best practices.

1.4.2.3 Maturity Models Related to Product Development in the Manufacturing Industry and Business Development

The Dooley's New Product Development Maturity Model (Dooley *et al.* 2001) is used to benchmark the capabilities of processes and determine the impact of maturity on project performance in new product development. This model was tested using a sample of 39 programs in new product development in the manufacturing industry.

The Object Management Group, a US based computer industry consortium, has developed the Business Process Maturity Model, BPMM (OMG, 2008). Its objective is to provide a technique for organizations to assess the maturity of processes, identify organizational strengths and weaknesses, and guide organizations to improve processes.

The Standardized Process Improvement for Construction Enterprises (SPICE) model is a five-stage maturity model developed based on the European Foundation for Quality Management/Business Quality Foundation-Business Excellence Model (EFQM/BQM) standard (Hutchinson and Finnemore, 1999). SPICE is a framework that helps the construction industry to evaluate processes, identify strengths and weaknesses of the organization, and suggest and prioritize business development process improvements.

Unfortunately, the maturity models investigated to date have focused on the maturity of the organizations and way that processes are managed and operated. The primary interest of this research work, however, was not related to the operation and management of work processes themselves, but to the process design aspects of the work processes and communications. That is, this research focuses more on if and how the processes were formalized, and less on how the processes were conducted and managed.

1.4.3 A Review of the Domain and Application Ontologies

One of the most common definitions of an ontology is "an explicit formal specification of the terms in the domain and the relations among them" (Gruber, 1995). There are some related ontologies in the domain of business modeling: the Resource-Event-Agent (REA) Ontology (Gaily *et al.* 2007) and the Open-edi Transaction Application Ontology (ISO, 2006). The Open-edi Onto is an expanded version of the Resource-Event-Agent Ontology (Allen and March, 2006) that is based on an accounting model, Resource-Event-Actor (McCarthy, 1982). The three terms refer to the economic resource (money or other financial resource), economic event (the time at which the financial resource is exchanged between the economic agents or actors), and economic agent or actor (the individuals who possess the economic resource). The core focus of these ontologies is on business modeling in terms of representing transaction concepts associated with the exchange of the economic resource between the seller and buyer roles based on reciprocity and duality. Both ontologies cover commercial transactions in which economic resource (money for goods) is exchanged between the parties as a result of the transaction; whereas the focus of this research work is on information transactions where information resource (information for information) is exchanged between the parties as a result of any interaction between the parties.

In the domain of infrastructure management, the three relevant ontologies; (i) IPD-Onto (Osman, 2007), (ii) the Infrastructure and Construction Process Ontology, IC-Pro-Onto (El-Gohary, 2008), and (iii) the Actor Ontology, Actor-Onto (Zhang and El-Diraby, 2009) have already been developed as part of the Semantic Collaborative Portal for the Exchange of Infrastructure Interdependencies Information—SCPEI3 project under the Joint Infrastructure Interdependency Research Program, JIIRP (El-Diraby, 2004). The development of the Trans_Dom_Onto as part of this research work is the author's contribution to the SCPEI3 project. One of the objectives of the SCPEI3 project was to develop ontologies in the domain of infrastructure management to overcome the problem of interoperability between heterogeneous information systems of the infrastructure organizations.

The IPD–Onto (Osman, 2007) represents infrastructure product knowledge (e.g. pipe, valve, pump, etc.). The IC-Pro-Onto represents process knowledge, e.g. core design and construction processes, management processes, knowledge integration processes, and support processes (El-Gohary, 2008). The Actor-Onto represents knowledge related to AEC/FM actors and actor-roles (Zhang and El-Diraby, 2009). A remaining deliverable in the SCPEI3 project (El-Diraby, 2004) is the Trans_Dom_Onto, which would specify "what and how" information (IPD-Onto) is to be exchanged between different actor-roles (Actor-Onto) in order to accomplish a given process successfully (IC-Pro-Ontology). As long as possible, the Trans_Dom_Onto have integrated and implemented some concepts from other infrastructure domain ontologies. The Trans_Dom_Onto supports the design, implementation, and management of transactions in the domain of infrastructure management and the development of the TFP.

While these three core formalism dimensions have been completed, there remains a need to formalize information exchange processes (transactions) to enable computer-to-computer, message-based exchange of information. Transaction formalism involves specifying and defining not only the process, actor and infrastructure system information, but also the specification of information exchange details, which is to be addressed through the development of the Transaction Domain Ontology (Trans_Dom_Onto). In addition, these ontologies do not completely support the design of the MTs that are required to be exchanged in the AI&CAR/TCA Reporting (information transaction). The IPD-Onto doesn’t represent a complete set of the infrastructure products, and it was extended in this research in terms of the TCAs to provide payload information for the design of the MTs for the AI&CAR/TCA Reporting. The header information in these MTs, meanwhile, is captured from the Tran_Dom_Onto that was developed as part of this research work.

According to Gomez-Perez *et al.* (2005), ontologies are built on four levels of abstraction. The *upper ontology* represents concepts that are the same across different industries, e.g. project, resource, actor. The *domain ontology* represents concepts in a specific domain of interest at a higher level of abstraction, e.g. transaction, message, transaction mechanism (transaction channel). The *application ontology* represents concepts that are specialized for a specific application, e.g. road, bridge, pipeline. The *user ontology* is developed from the perspective of a specific user of an organization. Both the Trans_Dom_Onto and TCA_Onto were developed following this layered architecture.

1.4.4 A Review of Process/Transaction Formalization Standards and Methodologies

Some process and communication formalization techniques currently exist both outside of and within the Architecture, Engineering, Construction and Facilities Management (AEC/FM) industries, but these standards do not fully address the requirements for transaction formalism in the domain of infrastructure management. This section reviews the most relevant of these standards.

In the non-AEC/FM industries, there are several standards of particular interest. The Open Electronic Data Interchange (Open-EDI) was one of the initial efforts related to the development and implementation of communication standards (ISO, 1995). The main focus of the standard was on modeling and standardizing business documents being exchanged between the parties. The disadvantages of the standard were its complexity, high cost of implementation, and high transaction costs. The United Nation's Center for Trade Facilitation and Electronic Business (UN/CEFACT) Modeling Methodology (UMM) focuses on understanding, modeling, and formalizing commercial transactions (buying and selling transactions) (UN/CEFACT, 2003). The electronic business Extensible Markup Language (ebXML) is a set of specifications that enables organizations of any size in any geographical area to conduct business over the internet using XML-based messages (ISO, 2004-05), while RosettaNet (RN) formalizes communications in the supply chain of the electronics industry (Damodaran, 2004). The UMM, ebXML, and RosettaNet focus on providing specifications for a specific set of commercial (e.g. purchasing) transactions and they do not define a detailed procedure for how others can produce their own transaction specifications. In contrast, objective of this research work is not to pre-define specifications for particular types of transactions, but rather to provide a process for practitioners to define their own transaction specifications to meet their individual needs. Each of these standards includes a component that provides the semantic definitions of the terms and concepts used in the specifications (UMM and ebXML use a core component specification and RosettaNet uses a business and technical dictionary); whereas the proposed TFP achieves this by developing ontologies.

A number of researchers have developed methodologies for business process modeling. Among these, Villarreal *et al.* (2006) have developed a model-based development process methodology that lacks the specification of a procedure that describes how to capture business processes and information requirements for the design of messages. Kim (2002) has developed a standardized schema to formalize business processes, but this approach lacks the complete procedure used to define business processes—it is not a complete methodology as it depends on the UMM for the design of business processes. Kramler *et al.* (2005) have developed a methodology to support the use of web service technologies in business collaboration in terms of modeling and delivery of process models; however, this does not include the way that information exchange requirements and message templates are defined. Bauer *et al.* (2004) developed a model-driven approach to design cross-enterprise business processes; however, it doesn't elaborate on the information modeling associated with these business processes.

In the AEC/FM industries, the Information Delivery Manual (IDM) formalizes work processes in the construction industry (IAI-IDM, 2007 and IAI-IDM, 2012). It is a requirement specification methodology focusing on model-based exchange of information between different parties using building information models (BIM). The IDM defines information in terms of informational elements (objects and their attributes) rather than informational products (documents), hence the methodology is BIM specific. In addition, the exhaustive nature of the IDM makes it time-consuming to develop and difficult to share with others on projects (Berard and Karlshoej, 2012). Because of the IDM's explicit focus on BIM, it does not meet the requirements for a general communication formalism technique for the infrastructure sector, but it is a very relevant exemplar for this research work, and therefore, some features of the IDM specifications were adopted with modifications as explained later in this chapter.

Like the IDM, the BIM project execution planning guide (PSU, 2011), focuses on the execution of the BIM over the life cycle of projects. The four core components of the guide are: identify BIM uses over the project life cycle, create a process map of BIM uses, define information exchanges in each use, and develop the implementation infrastructure (contracts, communication procedures, technology and quality control). The specific target of the guide is to define a BIM execution strategy over the project life cycle. The main emphasis is on 3D model-based exchange of information between different parties within the domain of the building industry, whereas the focus of this research work is on message-based exchange of information between the collaboration partners in the domain of infrastructure management. The Model View Definition (MVD) is a methodology developed to formally define a subset of an Industry Foundation Class (IFC) BIM model (IAI-MVD, 2005). The MVD is relevant since it is typically used to formally specify the particular BIM information to be exchanged during a specific type of data transaction, but again, it is BIM specific and it lacks a step-by-step procedure describing how to capture requirements. The Voorwaarden Scheppen Voor Invoering Standaardisatie (VISI), which means "Terms and Conditions for the Implementation of Standardization in ICT" is a Dutch communication management standard developed to define transactions in the AEC/FM industry (VISI, 2007 and VISI, 2011). The VISI standard lacks a step-by-step process to capture transaction requirements and define transactions, and it depends on an Extensible Markup Language (XML) based model representing information in a local context (i.e. the Dutch construction industry). A related standard, the Construction Objects and Integration of Processes and Systems Engineering Method (COINS-EM/CEM), is a Dutch standard developed to create agreements on working methods and organization of production processes and information (Schaap *et al.* 2008). As with the IDM, COINS-EM/CEM focuses on exchange of model-based/3D object data rather than communication in general, and it also lacks a systematic procedure for requirement specification. Another initiative, the agcXML, focused on developing a set of XML schemas to enable industry experts to exchange electronic building information reliably and efficiently among heterogeneous proprietary software applications to improve interoperability and integration of the information systems (Zhu, 2007). The scope of the agcXML doesn't include a general data transaction specification, it does include a format for transaction use cases and a use case for generic document distribution (Froese, 2007), but does not include a procedure for transaction design and management.

In summary, none of the standards discussed above fully meet all of the objectives of this research work in terms of developing a step-by-step procedure to define transaction specifications in the domain of infrastructure management. Most of the standards are work-process-centric rather than communication-centric. Most do not address how to assess needs and capture information that is required in a given communication. Most of the standards are IT-expert-centric and are not suitable for the end users. Of these existing methodologies, the IDM provides a good exemplar for the development of the proposed TFP. The IDM arose out of efforts within the international BuildingSMART community to establish the Industry Foundation Classes as an open BIM exchange standard. After many years of developing these BIM exchange standards, adoption was slow, in part because it was difficult to implement these standards both in software and in the end-user's work practices. Over time, it was determined that adoption could be improved if the BIM exchange processes are formally designed, documented, and agreed-upon—the IDM was then developed to support these formalisms of the BIM exchange transactions. The proposed TFP is intended to play a similar role in the infrastructure industry data transactions that the IDM plays for IFC-based BIM transactions.

1.5 Case Study

The TFP Tool was applied to one of the transactions identified through the IT survey conducted as part of this research work as having a high potential for IT improvement—AI&CAR/TCA Reporting. The municipal experts completed the needs assessment form using the assessment criteria developed as part of this research work: (i) manual/paper based transaction, (ii) critical transaction, (iii) costly transaction, (iv) frequent transaction, (v) likelihood of management, (vi) complex transaction, (vii) contractual requirement, and (viii) regulatory requirement. The AI&CAR/TCA Reporting transaction was selected because it scored high against the assessment criterion. Despite the fact that the frequency of this transaction is not high, the municipal experts identified it as one of the potential transactions because of three reasons: (i) *Compliance with regulatory requirements*—newly imposed regulatory requirements require municipalities to report asset inventory information in compliance with the Public Sector Accounting Board reporting requirements-3150 (PSAB, 2008) and condition assessment in compliance with the Statement of Recommended Practices, SORP reporting requirements (SORP, 2008); (ii) *Manual/paper based transaction*—currently, this transaction is manual as human interpretation of the information is required and organizations find it difficult and time consuming to compile, extract, and compare the TCA information, and (iii) *Costly*—this transaction is costly in terms of time spent in extracting and comparing information.

The AI&CAR/TCA Reporting case study transaction was used in three ways. *First,* the TFP Tool was applied to formalize this transaction to develop the transaction specification for the application area. *Second*, the transaction specification for AI&CAR/TCA Reporting was implemented to develop a prototype system—the AIIS. *Third,* the transaction specification developed for AI&CAR/TCA Reporting was managed for future use in a prototype ITMP developed as part of this research work. The second use of the case study is described in the following subsection.

1.5.1 Asset Inventory and Condition Assessment Reporting/Tangible Capital Asset Reporting Process

AI&CAR/TCA Reporting is a communication process in which different municipalities report their AI&CAR/TCA information to the provincial government for financial planning and funds allocation. The provincial government collects and analyzes this information to: (i) understand the long-term funding needs of different municipalities for infrastructure management; (ii) develop a consistent and planned approach to fund allocation; and (iii) to present the case to the federal government for additional funding, if required. This reporting also helps municipalities to update asset data on a regular basis, resulting in better management of their infrastructure systems.

- The As-is Asset Inventory and Condition Assessment Reporting/Tangible Capital Asset Reporting

The As-is AI&CAR/TCA Reporting is captured in Figure 1-7 where four different types of municipalities (i.e. city, town, district, village) exchange the TCA information with the provincial government using E-mail as the main mode of communication. Some issues with the As-is reporting are as follows:

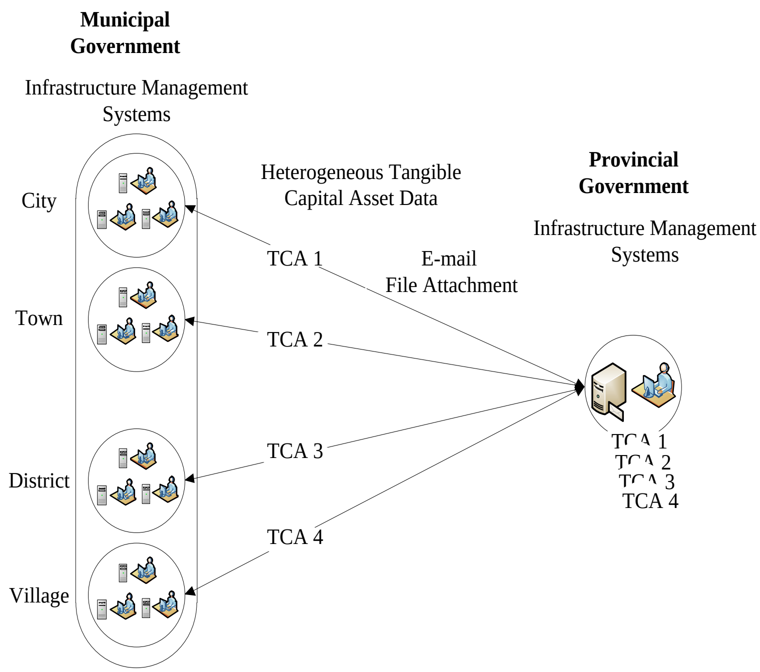

Figure 1-7 As-is asset inventory and condition assessment/tangible capital asset reporting

Manual—the As-is reporting is manual as the TCA information is exchanged as an E-mail report file attachment created in word doc(x) or PDF formats. In these reports, human interpretation is required at the receiving end, which makes the whole process time-consuming and prone to errors.

Heterogeneity—the provincial government receives the TCA information in different formats (e.g. TCA1, 2, 3 and 4, as shown in Figure 1-7) from city, district, town, and village municipalities as different municipalities use different information systems to manage their infrastructure systems. The reports generated from various municipalities differ in the definitions and groupings of the TCAs. The heterogeneity of the TCA information poses the following challenges; (i) it leads to the problem with the interoperability of the information systems, (ii) it makes the extraction, comparison, and analysis of data more difficult and time-consuming since manual interpretation of data is performed, and (iii) it hinders the development of standardized MTs.

Compliance with regulatory requirements—the As-is reporting process doesn't comply with PSAB-3150 reporting requirements for asset inventory (PSAB, 2008) and SORP reporting requirements of condition assessment (SORP, 2008).

Transaction history tracking—the As-is reporting process is E-mail based where provincial government communicates with most municipalities through E-mails, which makes it difficult to track the status of each AI&CAR/TCA Reporting transaction.

- The To-be Asset Inventory and Condition Assessment Reporting/Tangible Capital Asset Reporting

To address these issues, the To-be reporting process was proposed as shown in Figure 1-8 wherein municipalities make use of the formalized MTs (standardized TCA report/MT) to exchange the TCA information with the provincial government.

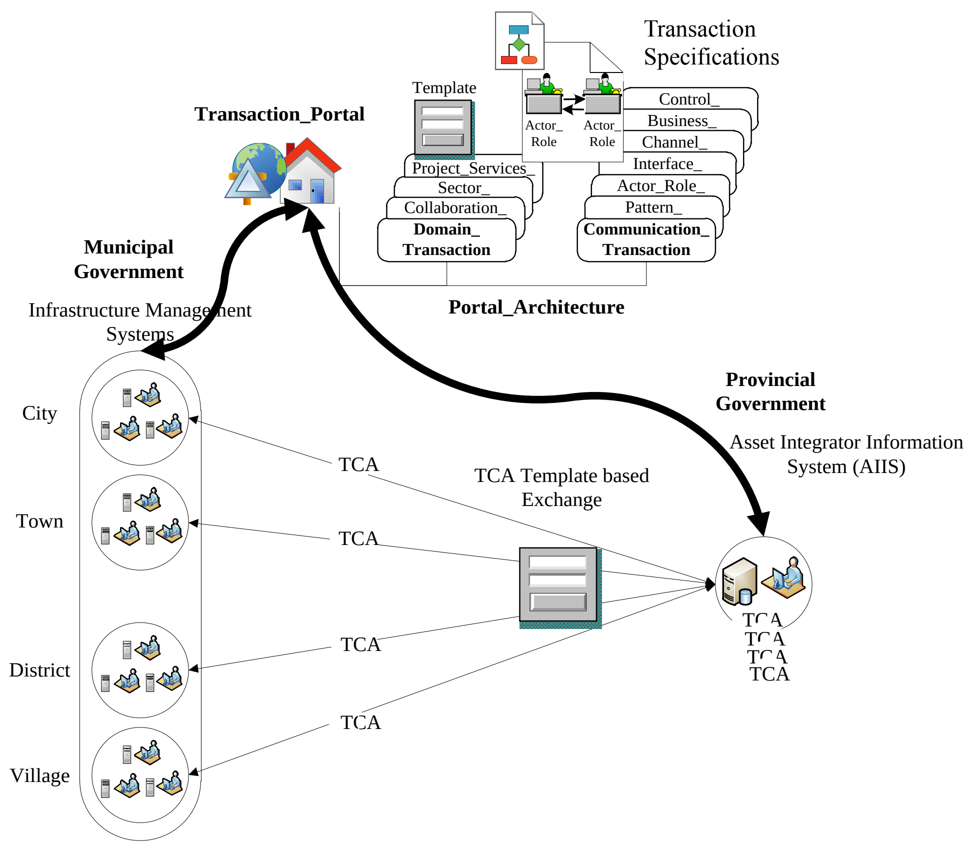

Figure 1-8 To-be asset inventory and condition assessment/tangible capital asset reporting

In the To-be reporting process, municipalities either download the formalized MTs from the ITMP developed as part of this research work or get a copy from the provincial government, fill in the required information, and send it to the provincial government through a prototype web-based AIIS. The AIIS performs basic functions such as: (i) send/receive TCA reports, (ii) create and store an instance of the formalized MT/TCA report, (iv) view all the previous transactions sent, and their responses, and (vi) send an automated acknowledgement message. The To-be reporting process improved the As-is process in three ways: (i) process formalization, (ii) information formalization; and (iii) channel formalization. In process formalization, messages were either automated or acknowledgement messages were added to the As-is reporting process that improved the way the TCA reporting is currently performed. In information formalization, the report was standardized through formalizing MTs in a way to comply with regulatory requirements as well as address the issue of data heterogeneity. In the channel formalization, the mode of communication was changed from E-mail based exchange to a template based exchange of information.

1.6 Thesis Organization

This dissertation uses a manuscript-based approach, organized into ten chapters based on the research objectives. Except Chapter 10, the remaining nine chapters represent one or more manuscripts that have either been published accepted, submitted for publication, or prepared for future submissions. The publication status is shown in Table 1-1.

Table 1-1 Thesis organization

Thesis Chapters	Research Objective based Thesis Organization		Publication Type	Publication Status
Chapter 1		Introduction	Conference	Published
	1	**Benchmark Initiatives**		
Chapter 2	a.	Benchmark IT Use & Identify Transactions	Journal	Published
Chapter 3	b.	Benchmark Transaction Formalism - Develop and Apply Infrastructure Management - Process Maturity Model	Conference	Published
			Journal	Published
	2	**Build Ontologies**		
Chapter 4	a.	Build Transaction Domain Ontology (Trans_Dom_Onto)	Conference	Published
			Journal	Published
			Journal	Draft
			Journal	Draft
			Book Chapter	Accepted
Chapter 5	b.	Build Tangible Capital Asset Ontology (TCA_Onto)	Conference	Published
			Journal	Published
	3	**Develop Protocol**		
Chapter 6	a.	Develop Transaction Formalism Protocol Specification	Conference	Published
			Journal	Published
Chapter 7	b.	Develop Transaction Formalism Protocol Tool	Journal	Submitted
	4	**Apply the Protocol to Develop, Manage, and Implement Transaction Specifications**		
Chapter 8	b.	Manage (Archive) Transaction Specifications - Develop Infrastructure Management Portal	Journal	Submitted
Chapter 9	c.	Implement Transaction Specifications - Develop Asset Information Integrator System	Conference	Published
			Journal	Accepted
Chapter 10		Conclusions, Contribution, and Recommendations		

NOTE: Sub-objective 4(a) is presented in Appendix K

Chapter 2 Survey on the Use of Information Technology

2.1 Introduction

One of the research questions set-forth in this research work was “What transactions are candidates to formalize? In response to the question an information technology (IT) survey was conducted in the domain of infrastructure management—Objective 1 (a) benchmark IT use and identify transactions. This chapter[2] is divided into five sections: introduction, related research work in the domain of interest, research methodology, IT survey results, and conclusions. The main purpose of the chapter is to describe the results of an IT survey that is accomplished as part of this research work. As a result of the survey, experts from the participating municipalities identified a set of transactions that has the greatest potential for IT improvement. In addition, the survey benchmarked the use of IT in terms of identifying the use of different types of software against a set of work processes and communications. The use of IT was also benchmarked through identifying various kinds of communication channels used in exchanging information between the parties involved in infrastructure management.

2.2 Review of the Related Research

Various IT surveys were studied in the global and North American context to identify the gaps. The primary references in the global context that were used to set-up the IT survey conducted in this chapter includes: Nordic IT Barometer Series (Howard and Samuelson, 1998; Samuelson, 2002; and Samuelson, 2008), Jordanian Barometer survey (El-Mashaleh, 2007), IT survey conducted in the Singapore construction industry (Hua, 2005), benchmarking study conducted for the New Zealand (Dohert, 1997), Nigerian (Oladapo, 2007), and Malaysian building and construction industries (Mui *et al.* 2002). Other important references include: Scheer *et al.* (2007) and Love *et al.* (2004) in the Brazilian and Australian AEC industries respectively. Detailed analysis of these references is given in Chapter 1, Section 1.4.1.1.

Some of the most important surveys that have investigated the state of IT in the North American context includes: the benchmarking study conducted by the Construction Financial Management Association (CFMA, 2008), survey of e-

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[2] A version of the chapter is published in the Journal of Information Technology in Construction.

Zeb, J.; Froese, T.; and Vanier, D. (2012). “Survey of Information Technology Use for Municipal Infrastructure Management”, Journal of Information Technology in Construction, ITcon Vol. 17, pg. 179-193, http://www.itcon.org/2012/11.

business implementation in the United States construction industry Issa *et al.* (2003), IT impact study (Rivard, 2000), and IT best practice studies in Canada (Rivard *et al.* 2004). A detailed discussion is given in Chapter 1, Section 1.4.1.2.

2.3 Survey Research Methodology

2.3.1 Phase 1—Survey Planning

Respondents were selected from local and regional governments, primarily municipalities in the province of British Columbia. Municipalities were categorized into four types based on the size of area and population: city, district, town and village. For the selection of a data collection mode, because of the relatively technical and complex nature of some of the research questions and the relatively small number of respondents expected, a combination of the initial web-based survey followed up with a researcher-administered face-to-face structured interview survey was chosen.

2.3.2 Phase 2—Survey Design

The questionnaire (attached as Appendix C) was divided into three parts containing a total of eight sections: (i) Part A, Section 1, general information about the respondents organizations and infrastructure systems; (ii) Part B, Sections 2 through 5, benchmarking IT use in infrastructure asset management; and (iii) Part C, Sections 6 through 8, examination of the methodology used to identify and define IT-based communication processes. Part A was a web-based questionnaire completed by respondents on-line, whereas Parts B and C were paper questionnaires completed by the interviewer during the face-to-face interviews. The survey methodology and questionnaire underwent an ethics review, which included protocols for the invitation and approval processes, data confidentiality, etc. (UBC, 2009).

2.3.3 Phase 3—Survey Execution

The first step in conducting the survey was to identify the target sample, or intended respondents. A sample refers to a part of the population that is representative of the entire data/population being studied (CSU, 2009). To calculate the minimum sample size for each of the classifications, a confidence level of 95% was assumed. Based on these parameters, a minimum sample size of five from each classification was sufficient to represent the target population. The sample size was calculated using the formula given at Appendix B, Section B.2. The population for this research work was the set of municipalities in Southwestern British Columbia, Canada (within a practical and economic travelling distance for the researchers to carry out face-to-face interviews). This population was divided into four strata: 15 city municipalities, 18 district municipalities, 08 town municipalities, and 05 village municipalities (population less than 2500). Within these 46 municipalities, 12 municipalities were participated. The survey sample and response profile are shown in Table 2-1.

Table 2-1 Survey sample and response profile

Type of Municipality	Municipalities Contacted	Municipalities Responded
City Municipalities, (Population > 5000)	15	8 (53%)
District Municipalities, (Area > 800 Hectare and Pop Density < 5 Pop/Hectare)	18	4 (22%)
Town Municipalities, (Population ≥2500 ≤ 5000)	8	0 (0%)
Village Municipalities, (Population < 2500)	5	0 (0%)
Total	**46**	**12 (26%)**

2.3.4 Phases 4 and 5—Survey Analysis and Reporting

The raw survey data were collected into summary tables and charts, and this processed data were analyzed as discussed in the subsequent sections. The final step in conducting the survey (to be completed) is the reporting of the results back to the municipalities and other interested parties.

2.4 Survey Results and Discussion

2.4.1 Benchmarking IT Use

IT use was benchmarked at two levels: (i) general IT use to support infrastructure management throughout the municipality, and (ii) IT use for specific infrastructure management functions within the engineering department.

2.4.1.1 General IT Use in Municipality

Respondents were asked to list the software used at the municipality level to manage infrastructure systems and to identify the processes accomplished with this software. Processes recorded were then grouped into five categories; planning and scheduling, design, finance and accounting, management, and monitoring, as described in Zeb *et al.* (2012). These work processes were carried out by the engineering, planning, utility, operation, finance, and administration departments of the municipalities. Most of the design work is entrusted to consultants; therefore, the use of the CAD software was limited only to modifications of the infrastructure network models prepared by the consultants. Similarly, the planning software is mostly used for program and portfolio management. Most of the municipalities were using up-to-date versions of the software, but some reported using older versions that were in need of upgrading.

2.4.1.2 Specific IT Use Within the Engineering/Public Works Department

IT use was assessed within the engineering/public works departments for the asset maintenance management planning work function (AMMP WF), a meta-level work process within the domain of infrastructure management to assess, analyze, and select the maintenance and rehabilitation alternatives. Vanier *et al.* (2006) have identified and defined six sub-processes of the AMMP WF: (i) asset inventory management; (ii) asset condition assessment; (iii) asset service life analysis; (iv) asset life cycle cost analysis; (v) asset risk analysis; and (vi) decision making analysis.

Respondents were asked to record the software used for each of these sub-processes, as shown in Figure 2-1. The x-axis shows the different software that the municipalities use to perform various work functions, the y-axis shows the percentage of municipalities that report using each software for the indicated work function, and z-axis represents sub-processes of the AMMP WF, identified earlier in this paragraph.

Of the six sub processes, the highest software use was for asset inventory management of water, wastewater, and road infrastructure. All 12 municipalities (100%) reported using software to support this work function, and they reported using a total 12 different software tools, The most common software being ArcGIS, which was used by 83% of the municipalities. There are three possible reasons for this level of computer support: (i) the importance of the process as a range of stakeholders from citizens to management staff require timely and accurate inventory information in order to perform various processes; (ii) the need for effective and efficient ways to store and retrieve a large set of asset information; and (iii) Canadian legislation related to the Public Sector Accounting Board Standard, PSAB-1350

(PSAB, 2009). The second highest level of software support was for asset condition assessment, with 67% of municipalities using at least one of eight different software tools (the most common software, dTIM was used by 25% of municipalities); 58% of municipalities used at least one of six different software tools for asset life cycle cost analysis; 50% used one of five different software tools for asset service life analysis; 50% used one of three different software tools for decision making analysis; and no one reported the use of any software tools for asset risk analysis. The lack of response for risk analysis was probably because any risk analysis carried out was completed by consultants who performed most of the modeling and design of municipal infrastructure projects.

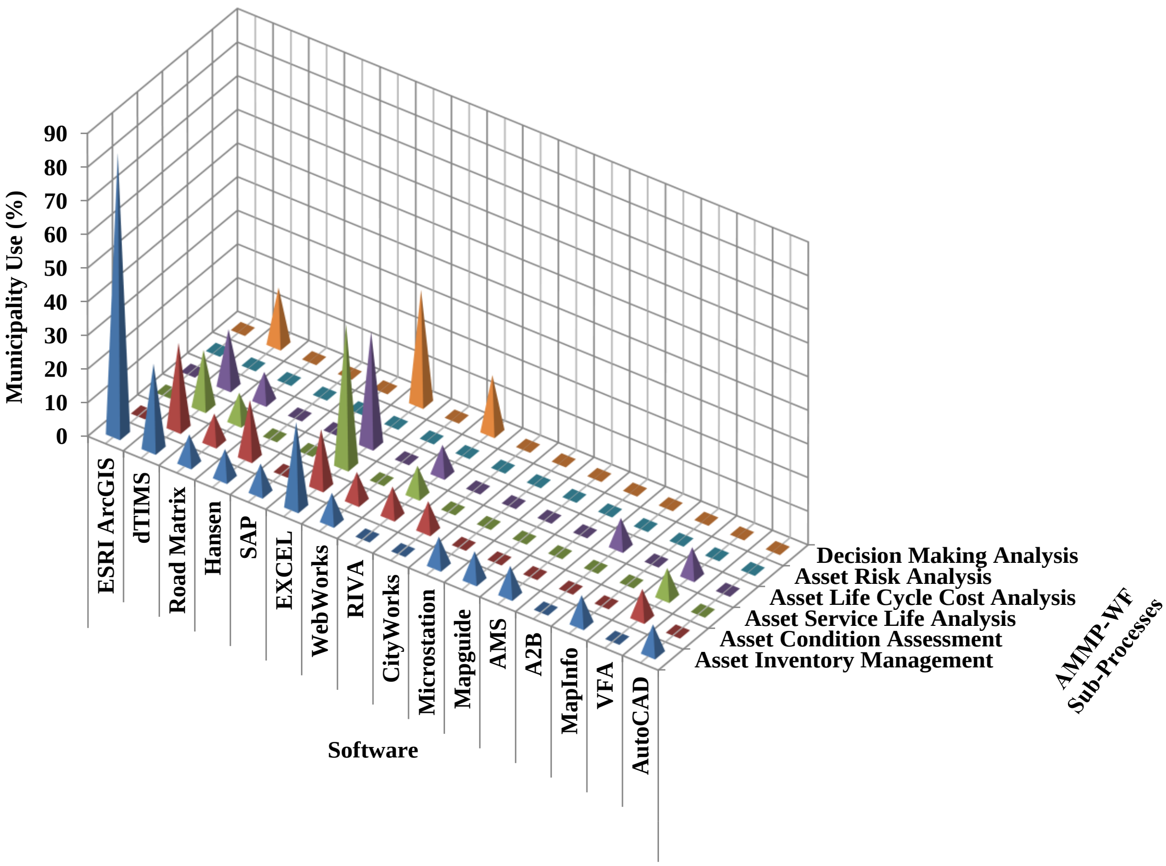


Figure 2-1 Software versus asset maintenance management planning work function

Sixteen different software systems are currently in use to manage different infrastructure systems in the surveyed city and district municipalities. Across all of the work functions carried out by all of the municipalities, the most commonly used software tools are Excel, followed by dTIM and then ArcGIS. The common use of Excel is due to its suitability, convenience, and pervasiveness for carrying out general technical calculations and data management, which are often sufficient for asset management processes. The use of the dTIMs was slightly higher than the ESRI Arc-GIS across the six sub-processes because most of the municipalities use dTIMs to accomplish most asset management processes, whereas ESRI Arc-GIS use was limited to asset inventory management only (for which most municipalities (83%) have installed ESRI Arc-GIS to deal with the largely GIS-based inventory data). The results indicating that the different levels of software use across different municipalities and the different work functions were found to be statistically significant using an analysis of variance (ANOVA) two-factor without replication technique (see Appendix A, Table A-1 for detailed analysis). The value of "F" in the ANOVA test was greater than "F_{crit}" (2.94>1.72) with p-value 0.00036 less than the alpha factor 0.050, indicating that the null hypothesis (no statistical difference between the degree of software use) is to be rejected and there is a significant difference between the use of these software applications to perform the six work processes of the AMMP WF.

Moreover, the use of different software in the city and district municipalities is presented in Figure 2-2. The x-axis represents various types of software; y-axis shows the percentage of the municipalities that use different software applications for the six work processes of the AMMP WF, and z-axis shows different types of municipalities.

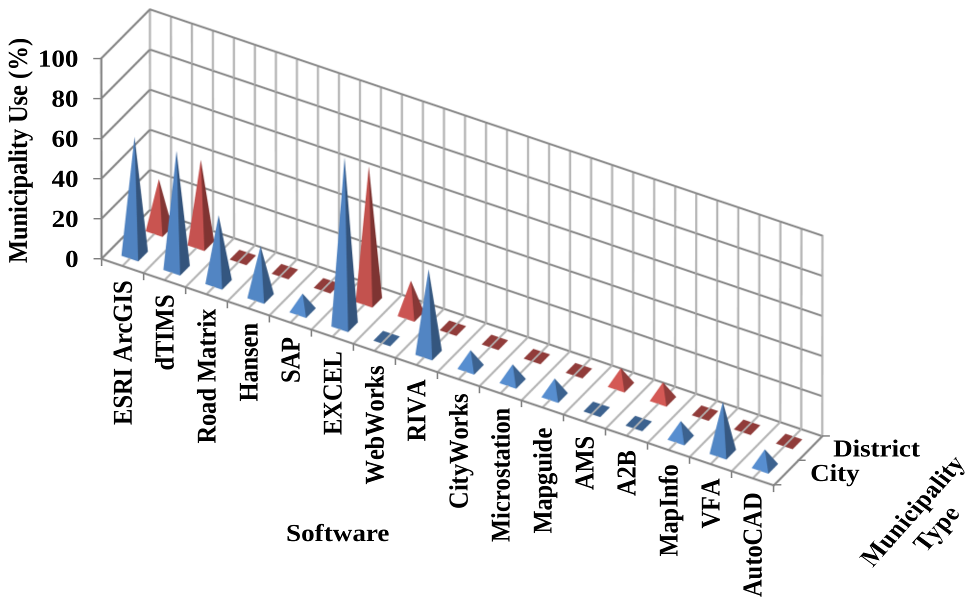
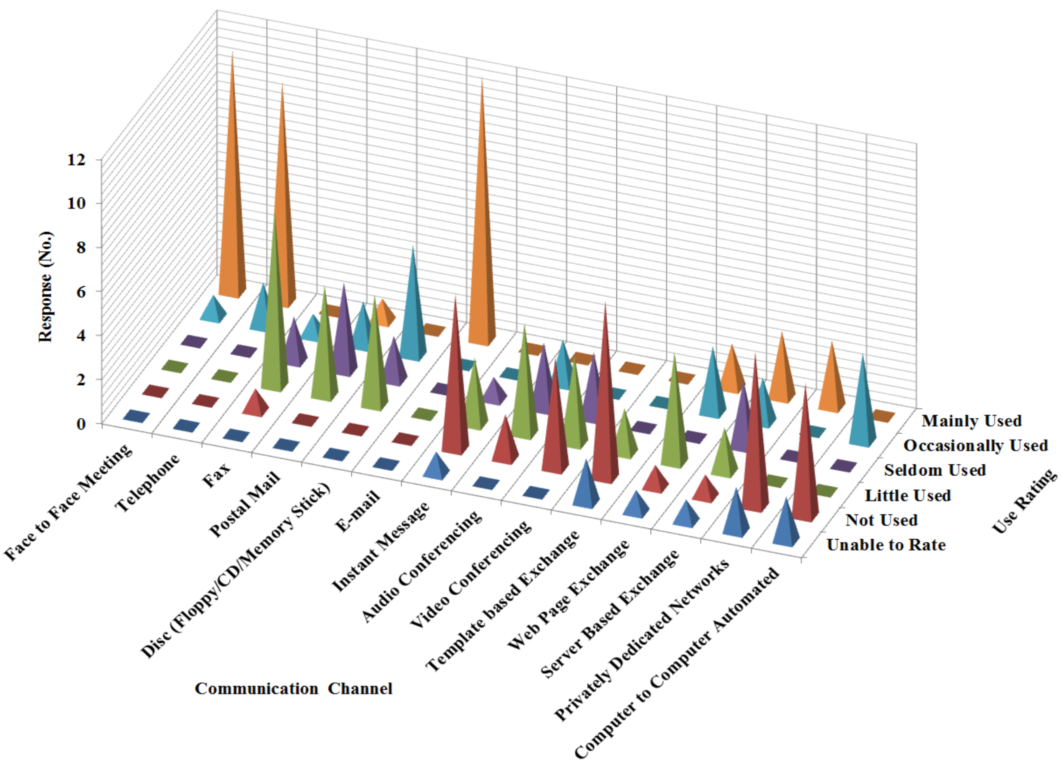


Figure 2-2 Software use in the city and district municipalities

Results indicate different levels of software use at the city and district municipalities, which was found to be statistically significant using an ANOVA two-factor without replication technique (see Appendix A, Table A-2 for detailed analysis). The value of "F" was greater than "F_{crit}" (10.47>4.54) with p-value 0.0055 less than the alpha factor 0.050, indicating that the null hypothesis is to be rejected and there is a significant difference between the use of these software in the city and district municipalities. The null hypothesis states that there is no statistical difference between the use of different software applications in the city and district municipalities to perform six work processes of the AMMP WF. The potential reasons for these differences include greater financial resources, human resources, and availability of required technical skills within city municipalities.

2.4.2 Benchmarking Communication Channels for Transactions

To benchmark communication channels, respondents were asked to record various channels they use for the exchange of information at two levels: general use at the municipality level and specific use at the engineering/public works department level. At the department level, various channels were recorded for the exchange of asset inventory and asset condition assessment information. Each channel was assessed against the following rating criteria: (i) the communication channel is not used; (ii) the communication channel is little used (once per six months); (iii) the communication channel is seldom used (once per month); (iv) the communication channel is occasionally used (once per week); and (v) the communication channel is the mainly used channel (once per day). Figure 2-3 shows the general use of different communication channels at the municipality level.



	Face to Face Meeting	Telephone	Fax	Postal Mail	Disc (Floppy/CD/ Memory Stick)	E-mail	Instant Message	Audio Conferencing	Video Conferencing	Template based Exchange	Web Page Exchange	Server Based Exchange	Privately Dedicated Networks	Computer to Computer Automated
Unable to Rate	0	0	0	0	0	0	1	0	0	2	1	1	2	2
Not Used	0	0	1	0	0	0	7	2	5	8	1	1	7	6
Little Used	0	0	8	5	5	0	3	5	4	2	5	2	0	0
Seldom Used	0	0	2	4	2	0	1	3	3	0	0	3	0	0
Occasionally Used	1	2	1	2	5	0	0	2	0	0	3	2	0	4
Mainly Used	11	10	0	1	0	12	0	0	0	0	2	3	3	0

Figure 2-3 Communication channel use at municipality level

Results indicate that face-to-face meetings, telephone, and E-mail were the main communication channels. Other than these main types of communications, all of the other types of channels received some use. For example, some municipalities report the use of the webpage-based exchange of information. This is the case where they have well-developed web sites with extensive information and, in some cases, users can explore and exchange information through submitting query, incident reporting, and approval applications. Similarly, some use of privately dedicated networks and server-based exchange of information was reported. This is where some municipalities have established file transfer protocol (FTP) servers through which they exchange large data files. The least-used channels are instant messaging and template-based exchange (i.e. essentially completing on-line structured data-field forms). Automated computer-to-computer communications were split between "not used" and "occasionally used", they have clearly come into existence within municipal communications, though they are not yet common place. Overall, the results suggest that, despite the prominence of the three main communication channels, municipal workers will resort to a very wide variety of other channels, both computer-based and non-computer-based, as the situation demands.

Figure 2-4 shows the communication channels used in the engineering/public works department level for the two specific communications of asset inventory and asset condition data reporting. Of the 14 communication channels, seven were used for the exchange of asset inventory and six for condition assessment data at the engineering services/public works department of the municipality. Again, a few communication channels are widely used (E-mail, face-to-face, server-based exchange, etc.), while a number of the communication channels saw no use.

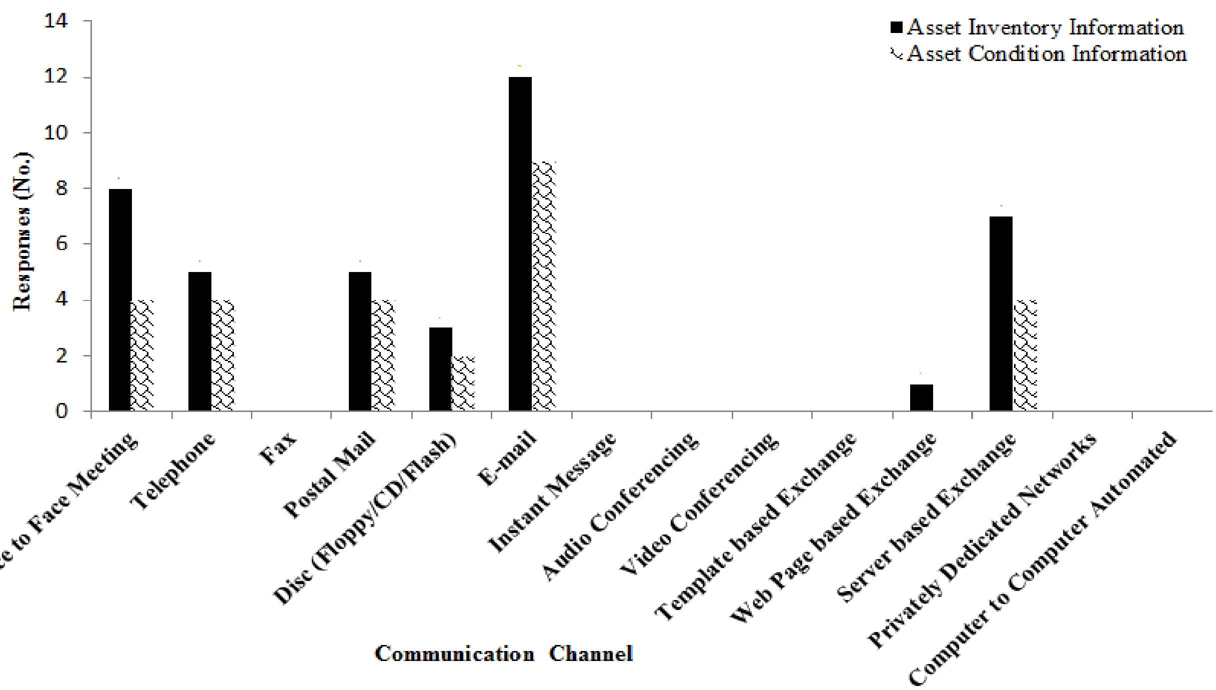


Figure 2-4 Communication channel use for asset inventory and condition assessment data

Analysis showed that there was sufficient data to confirm that these results showed a statistical difference between the communication channel usage. An ANOVA two-factor with replication technique (see Appendix A, Table A-3 for detailed analysis) showed that the value of "F" was greater than "F_{crit}" (27.59>2.08) with p-value 1.59E-12 less than the alpha factor 0.050, indicating that there was a significant difference between the use of 14 different channels for the asset inventory and condition assessment processes, and city vs. district municipalities. Overall, the results show that face-to-face meetings, telephone, postal mail, E-mail and server based exchange were commonly used channels by almost all city and district municipalities for the exchange of infrastructure information, indicating that the way information is currently exchanged is human-to-human, informal, unstructured, and is accomplished on an *ad hoc* basis. Computer-to-computer based exchange of information does not play a significant role in these technical communications.

2.5 Conclusions

This survey has been conducted to benchmark the range of information system that the municipalities use to perform diversified work processes, to benchmark communication channels to provide an insight on how municipal organization exchange infrastructure asset information; and to identify communications in the domain of infrastructure management that have the greatest potential for IT improvement. To achieve these objectives, a combination of web-based and face-to-face interview survey approach was used.

It was found that municipalities used a number of software applications to carry out the different work process. They were grouped into five categories: planning and scheduling, design, finance and accounting, management, and monitoring processes. A range of software applications was identified against each process category. Most of the municipalities were using an updated version of the applications. Sixteen software applications were identified to accomplish six sub-processes of asset maintenance management planning work function. The two most commonly used software were Excel and dTIMS. Moreover, the interoperability of these applications at the data level was more "between municipalities" in comparison to "within municipalities", where it was vice-versa at the information level.

Similarly, communication channels were benchmarked at the municipality and department levels. It was found that face-to-face meetings, telephone, postal mail, E-mail and server based exchange were widely used modes of communication in municipal infrastructure management, emphasizing that current practices of information exchange are human-to-human, informal, and unstructured, and are accomplished on an *ad hoc* basis. To improve current practices of information exchange, other modes of communication (e.g. template based or computer-to-computer automated) could be explored to achieve communication efficiency in terms of time, and effectiveness in terms of quality (right information to the right person at the right time), and cost.

As introduced at the beginning of this chapter, the survey was conducted as part of a larger research effort to improve computer-to-computer information exchange between infrastructure organizations. The results show that, while municipalities do not commonly use this form of communication at present, they do routinely use the types of computer applications for a range of infrastructure management functions that provide the necessary environment for more advanced and efficient communications to take place.

Chapter 3 Infrastructure Management—Process Maturity Model

3.1 Introduction

The second research question in this research work was "why formalize transactions?" or "how to assess transaction formalization?" In response to the question, an Infrastructure Management—Process Maturity Model (IM-PMM)—Objective 1 (b) benchmark transaction formalism, was proposed to assess the degree to which work processes and communications are formalized in the domain of infrastructure management.

This chapter[3] is composed of eight sections that discusses the development and application of the proposed IM-PMM. The IM-PMM consists of a set of elements (component-based) and stages (i.e. maturity-based). Three elements were identified and defined to assess the maturity of work processes, namely, process/transaction map definition, actor/actor role definition, and information definition whereas one additional element (message definition) was defined to assess the maturity of communications. The IM-PMM consists of five different stages of maturity: infancy, preliminary, reactive, proactive, and integrated. The stage of maturity of a work process and communication is assessed based on the elements mentioned above.

The proposed model was used to assess the maturity of work processes and communictions through a survey conducted in the Southwestern municipalities of British Columbia, Canada. The results of the survey indicate that the average maturity levels for communications were found to be slightly higher than for work processes. No statistically significant variations were observed between the overall maturity levels of the various elements assessed for the work processes, but a significant difference was observed between the different elements in communications. Also,

[3] A version of the chapter is published in the CIB W78—W102 Conference and Journal of Sustainable Development.

Zeb, J.; Froese, T.; and Vanier, D. (2011). "Development and Testing of a Process Maturity Model in the Domain of Infrastructure Management", Proceedings of the CIB W78—W102, October 26-28, 2011, Sophia Antipolis, France. This paper briefly describes the development and application of an Infrastructure Management Process Maturity Model.

Zeb, J.; Froese, T.; and Vanier, D. (2013). "Infrastructure Management Process Maturity Model: Development and Testing", Journal of Sustainable Development, Vol. 6, No. 11, Published by Canadian Center of Science and Education, doi:10.5539/jsd.v6n11p1; URL: http://dx.doi.org/10.5539/jsd.v6n11p1. This paper captures the detailed development and application of the Infrastructure Management Process Maturity Model.

significant differences in maturity were found between the city and district municipalities for both work processes and communications. In summary, the survey identified that work processes and communications are performed in an *ad hoc* way in the domain of infrastructure management.

3.2 Related Work in Process Maturity Models

The proposed IM-PMM was developed based on the review of the existing maturity models in the construction, software, and manufacturing industries. The primary references underlying the development of the proposed IM-PMM includes: Portfolio, Program, and Project Management Maturity Model (OGC-APM, 2010), Organizational Project Management Maturity Model (PMI, 2003), Berkeley's Project Management Maturity Model (Kwak and Ibbs, 2000), Interactive Capability Maturity Model (McCuen and Suermann, 2007), Indiana University BIM Proficiency Matrix (IU, 2009), Capability Maturity Model Integration (SEI, 2010), Dooley's New Product Development Maturity Model (Dooley *et al.* 2001), Business Process Maturity Model, BPMM (OMG, 2008), and Standardized Process Improvement for Construction Enterprises (SPICE) maturity model (Hutchinson and Finnemore, 1999). To identify gaps, a detailed analysis was conducted that is presented in Chapter 1, Section 1.4.2.

3.3 Methodology to Develop and Apply the Proposed Maturity Model

A five step methodology was devised as part of this research to develop and apply the proposed IM-PMM. The proposed methodology is a modified version of the procedure developed by Becker and Knackstedt (2009) for developing maturity models. The five steps are as follows:

i. *Define the problem*—the problem was first explicitly defined in terms of the needs assessment for the proposed IM-PMM.

ii. *Compare existing maturity models*—existing maturity models were compared to assess gaps explicitly and to develop strategies for the development of the proposed IM-PMM.

iii. *Develop the IM-PMM*—the proposed IM-PMM was developed based on the review of the existing maturity models and the strategies developed in the previous step.

iv. *Apply the IM-PMM*—the IM-PMM was tested by applying it to the domain of infrastructure management to test its' applicability.

v. *Evaluate the IM-PMM*—related to evaluating the proposed IM-PMM.

3.4 Comparison and Summary of Maturity Models

A set of maturity models was compared to assess the degree to which certain activities are managed in practice. A particular application of a maturity model assessment approach is characterized by the following two primary features:

- The assessment target—each maturity model is developed to assess a particular target: a specific domain, a type of process, or an explicit set of work processes and communications.

- The maturity scale—maturity models assess their targets with respect to a prescribed maturity level scale that measures the degree of formalization, sophistication, or completeness of the management of the target.

While each maturity model adapts and refines the discrete or continuous maturity levels to suit the specific context of their target, they typically progress through some form of the following stages of process formalization:

- The process is not being performed
- The process is performed in an *ad hoc* way (each actor develops their own approach)
- The process is formally defined, documented, and performed in a consistent way
- The process is actively managed, with process control, feedback, and continuous improvement

For this work, in assessing the formalization of work processes and communications in the infrastructure management domain, the same general approach was adopted as used by all of the above models of assessing target processes against maturity levels. None of the existing MMs were found to overlap suitably with the target domain of infrastructure management, therefore, a set of work processes and communications were defined based on the infrastructure management framework of Vanier *et al.* (2009), as described in Section 3.5.1. Moreover, all of the maturity models investigated to date have focused on the maturity of the way that organizations and processes are managed. The primary interest of this research;, however, is not in the operation and management of work processes themselves, but in the *process design* aspects of the work processes and communications. That is, the focus of this research work is more on *if and how* the processes are formalized, and less on how the processes are then conducted and managed. As a result, slightly different definitions of the maturity levels (stages) were developed (described in Section 3.5.2) than those used by the other maturity models discussed here. Finally, although maturity model approaches typically assess the maturity level of the work process as a whole, the IM-PMM separates out certain important elements or features of the work process or communications in order to examine the process design in more detail. The elements that are examined for each work process and communication are: process/transaction map definition, actor/role definition, information definition, and message definition (as explained in Section 3.5.3).

3.5 Development of the Infrastructure Management—Process Maturity Model

The IM-PMM consists of three components: work processes and communications that are to be evaluated, the maturity stages against which they are assessed, and the elements that are assessed for each work process or communication.

3.5.1 Work Processes and Communications Targets

The targets of interest for this study are work processes and communications within the domain of asset management. Vanier *et al.* (2009) define asset management as “a business process and decision-support framework that: (i) covers the extended service life of an asset; (ii) draws from engineering as well as economics; and (iii) considers a diverse range of assets”. The specific domain of interest for this research work is the infrastructure management work function related to analyzing and selecting maintenance and rehabilitation alternatives as part of asset management planning for water, wastewater, and road infrastructure systems. This area of interest and these three specific infrastructure systems were selected because they are typically managed and controlled by only one body (municipal government) and they are rarely supported, investigated in an integrated fashion, making it a suitable candidate for research. Drawing from the framework by Vanier *et al.* (2009), the following functions were taken as descriptions of the work processes to be assessed within the IM-PMM framework:

i. *Asset inventory management*—enumerating, listing and storing of the infrastructure asset information so that owners and managers of these assets are aware of what they own and where it is located.

ii. *Asset condition assessment*—evaluating the existing condition of the assets so that owners and managers of assets are aware of the existing performance levels of the assets they own.

iii. *Asset service life analysis*—determining the remaining or residual life of the assets based on prevailing condition assessment of the asset.

iv. *Asset life cycle cost analysis*—assessing the cost over the life cycle of the asset.

v. *Asset risk analysis*—evaluating the risks associated with the asset over its life cycle.

vi. *Decision making analysis*—analyzing the proposed alternatives leading to the selection of the best alternative for maintenance or rehabilitation of the asset.

In addition to these work processes, the IM-PMM was used to evaluate different types of communications in the area of infrastructure management that were identified in the course of this research to be common to many of the municipalities in the survey:

i. *Asset inventory reporting*—reports the existence, type, extent and location of infrastructure assets.

ii. *Asset condition reporting*—reports the current condition of infrastructure assets.

3.5.2 Maturity Stages

The IM-PMM assesses the work processes and communications against five stages of maturity that reflect increasing levels of formalization or process maturity. The proposed stages follow general conventions for maturity models and are defined as follows: *Infancy stage, (process formalism unawareness)*—in this stage, organizations carry out work processes or communications, but personnel are generally unaware that the work processes and communications can be formally defined, documented, and managed. *Preliminary stage, (process formalism awareness)*—in the preliminary stage, personnel are aware of the idea of process formalism and know about the importance and definitions of the four elements (i.e. process/transaction map, actor/role, information, and message definitions), but these are not defined or documented in the process/communication in question. Each respondent carries out their role in the process as he/she sees fit, with little consideration of explicitly planning or documenting the process. *Reactive stage, (process definition)*—in the reactive stage, personnel carry out some explicit planning of the four elements in an *ad hoc* manner. The definitions are specific to a particular situation and they are dynamic and change frequently with time and context. The definitions are not documented for the purpose of future re-use. *Proactive stage, (process standardization)*—in the proactive stage, personnel define and document the four elements for future re-use, so that these work processes and communications are standardized over time. *Integrated stage, (process management)*—in the integrated stage, processes are actively managed against the standardized process definitions. Data is collected to determine effectiveness of work process and communications, and on-going process/communication improvements are pursued.

3.5.3 Work Process and Communication Elements

The four elements of work processes and communications are defined as follows. The design of a work process is characterized by the first three elements and the design of a communication is characterized by all the four elements. A work process or communication is said to be successfully designed if these elements are formalized properly. *Process/transaction map definition*—identifies and describes the activities to be completed and specifies the sequence or workflow logic linking the activities (IAI-IDM, 2007 and IAI-IDM, 2012). *Actor/role definition*—identifies actors (individuals/organizations), who play certain roles in a given context. To formally describe work processes and communications, it is beneficial to define actors and their roles in a given context. *Information definition*—assesses the degree to which the information inputs and outputs (i.e. to/from a work process, or the information content of a communication) are formally identified and described. *Message definition*—specifies representation and format of the information (i.e. fully-structured, semi-structured or unstructured messages). This may not be significant for work processes, but it is quite important for communications.

Figure 3-1 shows the overall assessment rubric for the proposed IM-PMM, with different elements on the vertical axis: three elements for work processes plus a fourth element for communications, the maturity stages on the horizontal axis, and the corresponding interpretations in the intersecting cells.

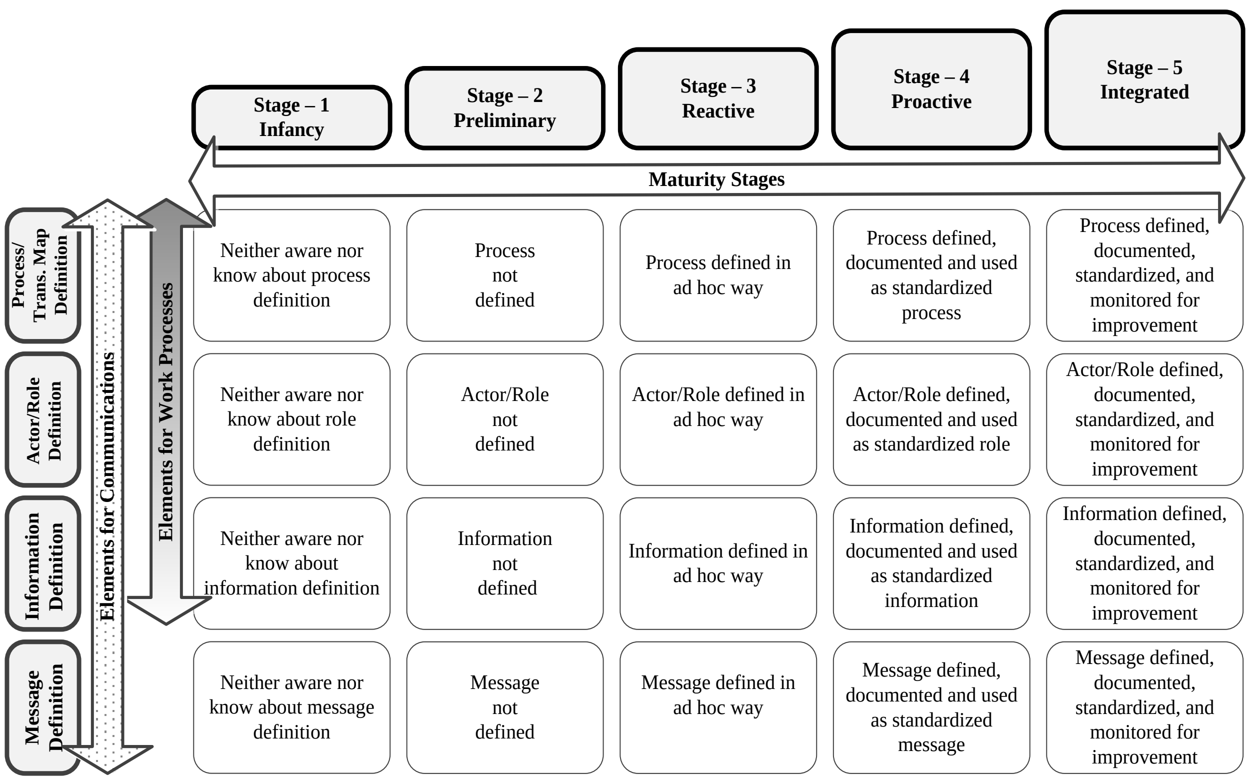


Figure 3-1 The infrastructure management—process maturity model, rubric for assessing infrastructure work processes and communications

3.6 Application of the Infrastructure Management Process Maturity Model

After developing the IM-PMM, the next step was to conduct a survey of selected municipalities, that is, how one can apply the IM-PMM to infrastructure management work processes and communications. The objective was to benchmark the level to which work processes and communications are formalized in infrastructure asset management practice, as well as to validate that the proposed IM-PMM is applicable. For planning and design of the survey, please see Chapter 2, Section 2.3.1, and Section 2.3.2 while target population is discussed in Chapter 2, Section 2.3.3.

3.7 Analysis of Survey Results

Figure 3-2 presents the survey results in three dimensions and Table 3-1 presents the data in tabular form. The x-axis of Figure 3-2 represents the four elements, and then further decomposes each element into the five possible maturity stages (1–5). The identified work processes and communications are shown along the y-axis (into the page), while the z-axis (vertical) identifies the number of responses received for each element (represented in x-axis) and each of their maturity stage (sub x-axis). The work processes (six asset management sub-processes, described earlier) are represented in Figure 3-2 by different hatched cones and communication processes are shown using hatched cylinders.

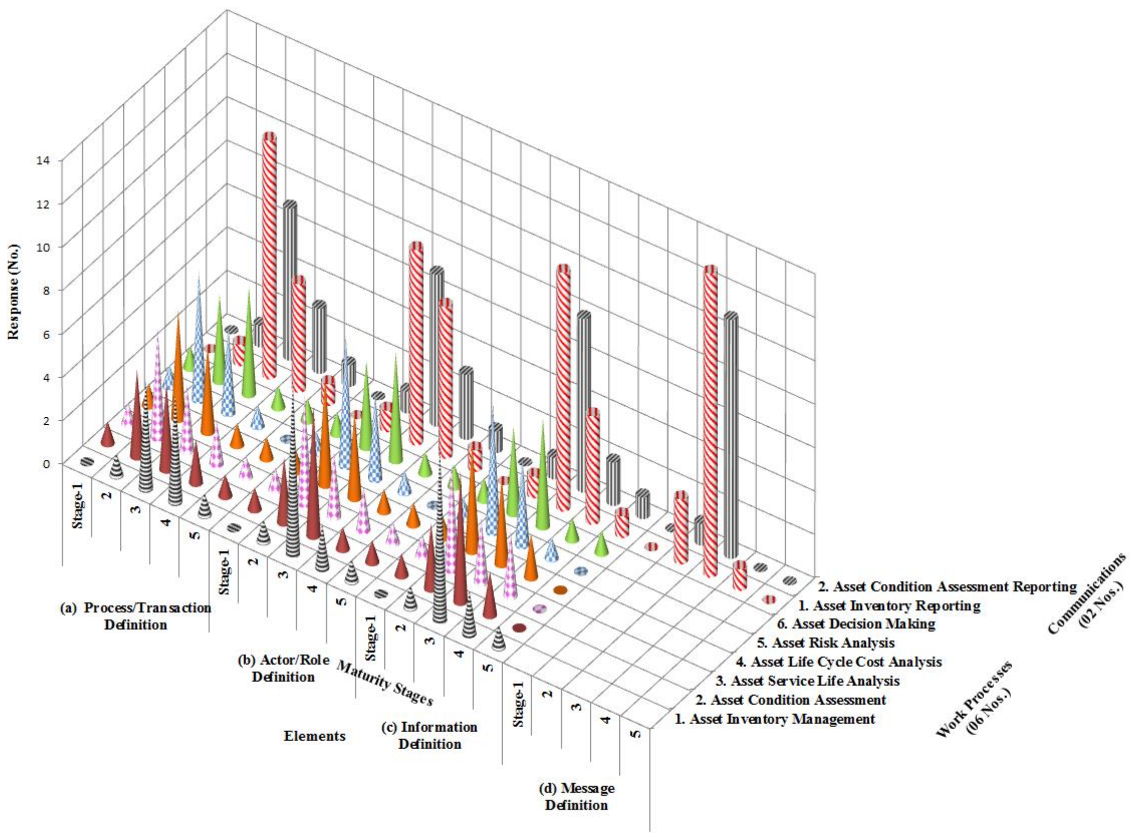


Figure 3-2 Benchmarking results showing the work processes and communications studied, the elements evaluated, and the number of responses found for each maturity stage

Table 3-1 presents portions of the survey results in a tabular form. The columns represent the responses per maturity stage in terms of the number of processes surveyed and the responses per element in terms of the sum of points scored.

For the response per stage (left columns), responses were recorded for each process against each stage of the process maturity. For the response per element (right columns), responses were recorded for each process against each element of the proposed IM-PMM as a point scored. Each element was assigned a point value that was calculated as the product of the response and respective level. The last two columns show the average of the sum of points scored for each element and the percentage (+/-) above or below the total average of 2.91. The top rows of the table show the six work processes and two communications. The bottom four rows show the totals in terms of the sum of responses per stage for all work processes and communications, with corresponding percentages and the average of the sum of points scored for each element. The survey results are analyzed, compared, and discussed in the following subsection.

Table 3-1 Work processes and communications—total responses per stage and responses per element

	Response/Stage in terms of the Number of Processes						Response/Element in terms of Sum of Points Scored					
Work Processes and Communications	**Stage-1**	**Stage-2**	**Stage-3**	**Stage-4**	**Stage-5**	**Total**	**Process/ Transaction Map**	**Actor/ Role**	**Information**	**Message**	**Average**	**(+/-) Average**
Work Processes												
Asset Inventory Management	0	3	21	9	3	36	3.50	3.25	3.25		3.33	21%
Asset Condition Assessment	3	10	16	5	2	36	2.81	2.80	2.76		2.79	1%
Asset Service Life Analysis	3	15	9	7	2	36	2.75	2.75	2.67		2.72	-1%
Asset Life Cycle Analysis	3	15	12	4	2	36	2.63	2.63	2.59		2.62	-5%
Asset Risk Analysis	3	18	12	3	0	36	2.39	2.39	2.39		2.39	-13%
Asset Decision Making	3	12	15	3	3	36	2.72	2.72	2.72		2.72	-2%
Communications												
Asset Inventory Reporting	0	6	45	18	3	72	3.37	3.48	3.37	2.92	3.29	1%
Asset Cond. Assess. Reporting	0	4	33	8	3	48	3.30	3.30	3.25	2.92	3.19	-1%
Total (%) and Avg.	15(4%)	83(25%)	163(49%)	57(17%)	18(5%)	**336**	2.93	2.92	2.88	2.92	2.91	
Total and Avg.-Work Processes	15	73	85	31	12		2.80	2.76	2.73		2.76	
Total and Avg.-Communications	0	10	78	26	6		3.34[a]	3.39[b]	3.31[c]	2.92	3.24	
Avg.-Communications (a, b, & c)								3.35				-13%

3.7.1 Typical Maturity Levels

The first observation that can be made about the results relates to the typical maturity levels identified from the survey. In general, relatively few respondents (15 or 4%) assessed their municipality at maturity stage 1 (i.e. infancy). One quarter (83 or 25%) assessed their municipality at maturity stage 2 (i.e. preliminary). The most common maturity level (163 or 49%) was stage 3 (i.e. reactive) where respondents follow *ad hoc* practices to define work processes and communications. At this level, respondents are aware of the four elements and use them to formalize the work processes and communications, but the process design is situation specific (*ad hoc*) and no process design documentation is maintained for future reuse. Few samples were found to be at higher maturity levels, with 17% or 57 respondents at stage 4 (i.e. proactive), where respondents make use of the elements to define the processes, standardize these processes and document them so that they can be reused in the future and 5% or 18 respondents assessed their municipality at maturity stage 5 (i.e. integrated), where work processes and communications are actively managed against the formal definitions and continuously monitored for improvement. This distribution gives an overall average maturity level of 2.91, suggesting that infrastructure practitioners are generally aware of and engaged in these processes and routinely define these processes, but that these process definitions are most commonly *ad hoc*, and are rarely being recorded, applied consistently, or actively managed against the four elements.

3.7.2 Comparison of Different Work Processes and Different Communications

The six aforementioned work processes all yielded similar levels of maturity for the first three elements (2.80, 2.76, 2.73 respectively) with an average level of 2.76 as shown in Table 3-1. The only significant variations from this was that the inventory management process was 21% higher than the average of 2.76 for work processes with an average maturity level of 3.33 while the risk analysis process was 13% lower with an average maturity level of 2.39. Analysis of variance (ANOVA) analysis was performed to show that the differences between the different work processes were statistically significant as shown in Table 3-2, Test 1 (see Appendix B, Table B-1 for detailed analysis).

Table 3-2 Results of tests for statistical significance using ANOVA technique

Test	Null Hypothesis	F	Fcrit	P	Alpha	Result
1	The processes being analyzed have no significant difference	87.9	3.32	6.19E-08	0.05	Null hypothesis rejected
2	The communications being analyzed have no significant difference	5.87	10.12	0.09	0.05	Null hypothesis accepted
3	The elements being analyzed have no significant difference	2.24	4.1	0.15	0.05	Null hypothesis accepted
4	The four communication elements being analyzed have no significant difference	31.7	9.27	0.008	0.05	Null hypothesis rejected
5	The work processes maturity being analyzed in the city and district municipalities have no significant difference	462.25	4.17	8.84E-20	0.05	Null hypothesis rejected
6	The communications maturity being analyzed in the city and district municipalities have no significant difference	320.06	5.31	1.05E-11	0.05	Null hypothesis rejected

The following are the three possible contributing factors from these results. *First*, these six processes are roughly sequentially-dependent, in that the later processes require the input of the earlier ones, but not vice-versa. For example, inventory management can be achieved without performing any condition assessment, but condition assessment can only be carried out having some form of an asset inventory system. Therefore, it is to be expected that the first process of inventory management is likely to be more developed than the others. *Second*, condition assessment and performance prediction are often contracted out to consultants, so municipalities are likely to have less direct involvement with these processes and thereby less communication requirements. *Third*, the recent Canadian legislation related to implementation of the Public Sector Accounting Board-3150 (PSAB, 2009) requires Canadian municipalities to report their TCAs information in a consistent manner on their annual financial statements; this has prompted municipalities to formalize their management of infrastructure inventory, their estimation of the cost of assets and their calculation of remaining asset life.

As can be seen in Table 3-1, the process/transaction map of the asset inventory management sub-process was assessed as the highest of all samples; with an average maturity level of 3.50. Figure 3-2 shows that approximately half of all samples are assessed at levels 4 or 5. These averages for those work processes are consistent with previous municipal infrastructure surveys (Vanier and Rahman, 2004). These numbers suggest that higher levels of formalization are possible where there are sufficient drivers, such as PSAB 3150. In contrast, the asset risk analysis work process can be seen as a slightly less formalized process because municipalities mostly contract out project design and execution to consulting organizations that perform a risk analysis as part of the overall project. In addition, the risk analysis process is complex, requiring specialized software and expertise to perform it. An ANOVA analysis confirmed that there was no significant difference found between the maturity levels of the two different types of communications as shown in Table 3-2, Test 2 (see Appendix B, Table B-2 for detailed analysis).

3.7.3 Comparison of Different Elements

Different elements on the x-axis in Figure 3-2 were also compared with work processes and communications separately as shown in Table 3-2, Test 3 (see Appendix B, Table B-3 for detailed analysis). It was found that no statistically significant variations were observed between the overall maturity levels of the various elements assessed for the infrastructure processes. However, for infrastructure communications, statistically significant differences were found between different elements as shown in Table 3-2, Test 4 (see Appendix B, Table B-4 for detailed analysis). The first three elements were all similar with an average maturity level of 3.35, while message definition was 13% lower with an average maturity level of 2.92, indicating that the specification for message formats is not as widespread as the other elements. This may reflect the fact that the message definitions are currently intended more for communications that will be carried out by humans rather than computer-to-computer.

3.7.4 Work Process versus Communications

The average maturity levels for communications in Table 3-1 were found to be a little higher than for work processes (3.24 versus 2.76). This is probably not a significant finding since all organizations were asked about the same work processes, while organizations were invited to self-report the maturity level of their own communications. This self-reporting on communications would likely skew the results towards those transactions that the organizations had more formally defined and would omit transactions for which the respondents were not aware.

3.7.5 Comparison of Cities versus Districts

Statistically significant differences were found between the city and district municipalities for both work processes and communications maturity as shown in Table 3-2, Test 5 and 6 for the ANOVA techniques results, (see Appendix B, Table B-5, Table B-6 respectively for detailed analysis). The average maturity levels of processes in the city and district municipalities were calculated to be 2.13 and 0.78 respectively (not shown in Table 3-1), which means processes are more formalized and defined in more populous cities in comparison to less densely populated district municipalities. The potential reasons for these differences include: availability of more financial and human resources to the city municipalities, availability of the technical skills required to model and design processes, management vision and support to gain operational efficiencies through well-defined processes, and the use of the latest IT in the city municipalities (i.e. IT inherently requires more formalization of processes and communications).

3.7.6 Overall Interpretation

The overall interpretation of the survey results is that infrastructure organizations are routinely engaged in these infrastructure management processes, and that the notion of defining these work processes and communications is fairly common. However, the survey finds that these process definitions are currently very *ad hoc*, and there is a minimal application of standardized process formalizations, or active process management based on the process definitions (e.g. collecting process control data and pursuing continuous process improvement). The fact that some processes showed higher levels of formalization and that some infrastructure organizations were assessed at higher maturity levels indicates that the higher levels of formalization are possible within industrial practice when suitable drivers exist, such as: expertise of the staff to define processes, policies within the organizations to define and standardize work processes and communications, and prevalent use IT requiring processes to be formalized, etc.

These findings are significant because they show that the industry does not currently practice the highest degree of process formalization necessary for these work processes and communications and, more specifically, for what can be implemented in advanced computer-based systems. It appears that better awareness of current best practices and better support tools in the industry, and their successful implementation, could lead to increased process formalization in most municipalities. The IM-PMM could be used in future to identify any such opportunities for increased process formalization. It is believed that higher levels of process formalization are required in order to support the development and implementation of advanced computer-based communication systems. Furthermore, although no evidence was collected to support this assertion; it is hypothesized that higher levels of process formalization would lead to better management practices and better management of civil infrastructure systems.

3.8 Conclusions

To better serve society, infrastructure organizations must deliver their services in an efficient and effective way. The potential exists to improve the management of civil infrastructure systems using advanced information systems. As information systems continue to evolve towards integration and automation, work processes and communications must increasingly be defined and formalized, thus transforming prevailing informal practices of information exchange between humans to more formal and well-defined work processes and communications.

In order to benchmark work processes and communications in the domain of infrastructure management, an IM-PMM was developed to assist organizations to position themselves on a process maturity continuum. The IM-PMM developed as part of this research work has five maturity stages along three core elements (namely, process/transaction map definition, actor/role definition, and information definition) to benchmark six asset management work processes, plus one additional element (i.e. message definition) to benchmark two asset management communication processes. Benchmarking was carried out using face-to-face interviews with experts from different city and district municipalities.

From the analysis of the results, it is concluded that the work processes that are earlier in sequence (i.e. asset inventory management and condition assessment) are relatively better defined and formalized in comparison to later and more complex work processes like risk analysis and decision making analysis. No statistically significant variations were observed between the overall maturity levels of the various elements assessed for the work processes, but a significant difference was found between the different elements in communications. Moreover, the average maturity levels for communications were found to be slightly higher than for work processes. Also, significant differences in maturity were found between the city and district municipalities for both work processes and communications. In summary, the survey identified that work processes and communications are generally performed in an *ad hoc* way in the domain of infrastructure management. Given the context, work processes and communications need to be better defined and formalized in order to help implement advanced information systems that, in turn, will help manage civil infrastructure systems more efficiently.

The contribution of this research is the development of the proposed IM-PMM; whereas the contribution to practice is its application in the domain of infrastructure management to assess the level to which work processes and communications are formalized. The proposed IM-PMM can enable transaction development personnel to benchmark their work processes and communications in the domain of infrastructure management from the aspect of process design, which means how processes and communications are formalized and designed and not on how these are conducted and managed. The limitations of the study in relation to generalizeability is the limited application of the proposed IM-PMM industry-wide, country-wide, department-wide, and process-wide. A policy framework from senior levels of government and industry leaders is suggested to map out ways of driving the industry towards higher levels of process formalization in order to better manage civil infrastructure systems.

It is strongly recommended that the proposed IM-PMM be applied in other domains to test for generalizeability. *Industry-wide application*—the proposed model needs to be applied in various industries to examine its applicability in various industries including the entire AEC/FM industry. *Country-wide application*—the proposed MM should be applied in different municipalities across the country to broaden its spectrum. *Department-wide application*—the IM-PMM should also be applied within different departments of the same municipality to test its applicability. *Process-wide*—the proposed MM also needs to be applied to various processes within the same department.

Two different policy frameworks need to be developed for city municipalities and for district municipalities since there are significant differences found in their respective level of maturity. The strategies and policy recommendations contained in these two frameworks should address how higher levels of process formalization can: (a) support the development and implementation of advanced computer-based communication systems; (b) lead to better management practices; and (c) lead to better management of civil infrastructure systems. The proposed research also needs to be validated in the future by industry experts as part of the evaluation process.

Chapter 4 Transaction Domain Ontology

4.1 Introduction

The third research question set-forth in this research work was "how to formalize and manage transactions?" The first part of the question, "how to formalize transactions" was dealt with developing a set of ontologies—Objective 2, build ontologies and a Transaction Formalim Protocol (TFP)—Objective 3, develop a protocol. The two ontologies developed as part of this research work are Transaction Domain Ontology (Trans_Dom_Onto)—Objective 2 (a) and Tangible Capital Asset Ontology (TCA_Onto)—Objective 2 (b), which are discussed in Chapter 4 and Chapter 5 respectively. The proposed TFP was developed from two different perspectives; the TFP Specification—Objective 3 (a) and TFP Tool—Objective 3 (b), which are discussed in Chapter 6 and 7 respectively. Moreover, the second part of the question "how to manage transactions?" was dealt with developing an Infrastructure Transaction Management Portal (ITMP) that is discussed in Chapter 8.

This chapter[4] consists of eight sections, which describes the development, application, and evaluation of the Trans_Dom_Onto in the area of infrastructure management. The Trans_Dom_Onto represents the knowledge to support the design, management, and implementation of transactions in the domain of municipal infrastructure management. The knowledge in the Trans_Dom_Onto was organized according to core concepts (including;

[4] A version of this chapter has been published in the Candian Journal of Civil Engineering, based on an earlier version published in the proceedings of the annual conference of the Canadian Society for Civil Engineering. In addition, material presented in this chapter has been accepted as a book chapter for a monograph on ontologies in the Architecture, Engineering, and Construction industry to be published by the American Society of Civil Engineers.

Zeb, J. and Froese, T. (2011). "Design and Management of Transactions in the AEC/FM Industry Using an Ontological Approach", 3rd International/9th Construction Specialty Conference, Canadian Society of Civil Engineering, June 14-17, 2011, Ottawa, ON, pp. CN-021-1~10. The core focus of this paper was on development, application, and verification of the Transaction Upper Ontology and Transaction Domain Kernel Ontology.

Zeb, J. and Froese, T. (2012). "Transaction Ontology in the Domain of Infrastructure Management", Canadian Journal of Civil Engineering, Published by NRC Research Press, 39(9): 993-1004 (2012), doi:10.1139/L2012-054. The focus of this paper was on the development, application, and evaluation of the Transaction Domain Extended Ontology.

Zeb, J. and Froese, T. (2014). "Transaction Formalization in the Infrastructure Management Using an Ontological Approach", Accepted for Publication in the Book Titled "Ontology in the AEC domain: A Decade of Research and Developments." The book chapter captures a holistic view of the knowledge represented in the Trans_Dom_Onto and TCA_Onto, to show how the knowledge represented in these ontologies supports the design, management, and implementation of transactions in infrastructure management.

transaction, message, actor, actor role, and information) and support concepts (including; attribute, modality, relationship, constraint, mechanism, and axiom). The transaction and message concepts are discussed in this chapter and the remaining core and support concepts are described in Appendix E. The Trans_Dom_Onto evaluation and a potential area of application is discussed towards the end of this chapter.

4.2 Previous Research in the Area of Ontology Development

The Trans_Dom_Onto was developed based on the review of the state-of-the-art ontologies and standards in the domain of infrastructure management. The primary references underlying the development of the Trans_Dom_Onto is the Infrastructure Product Ontology, IPD-Onto (El-Diraby, 2006), the Infrastructure and Construction Process Ontology, IC-Pro-Onto (El-Gohary, 2008), and the Actor Ontology, Actor-Onto (Zhang and El-Diraby, 2009). Moreover, the knowledge represented in the Trans_Dom_Onto was captured from state-of-the-art work process and communication standards that includes ebXML (ISO, 2004) and RosettaNet (RosettaNet, 2004). Detailed analysis of these references is given in Chapter 1, Section 1.4.3 and Section 1.4.4.

4.3 Developing the Transaction Domain Ontology

4.3.1 Ontology Architecture

The development of the Trans_Dom_Onto in this research followed the layered architecture described by Gomez-Perez *et al.* (2005) as shown in Figure 4-1.

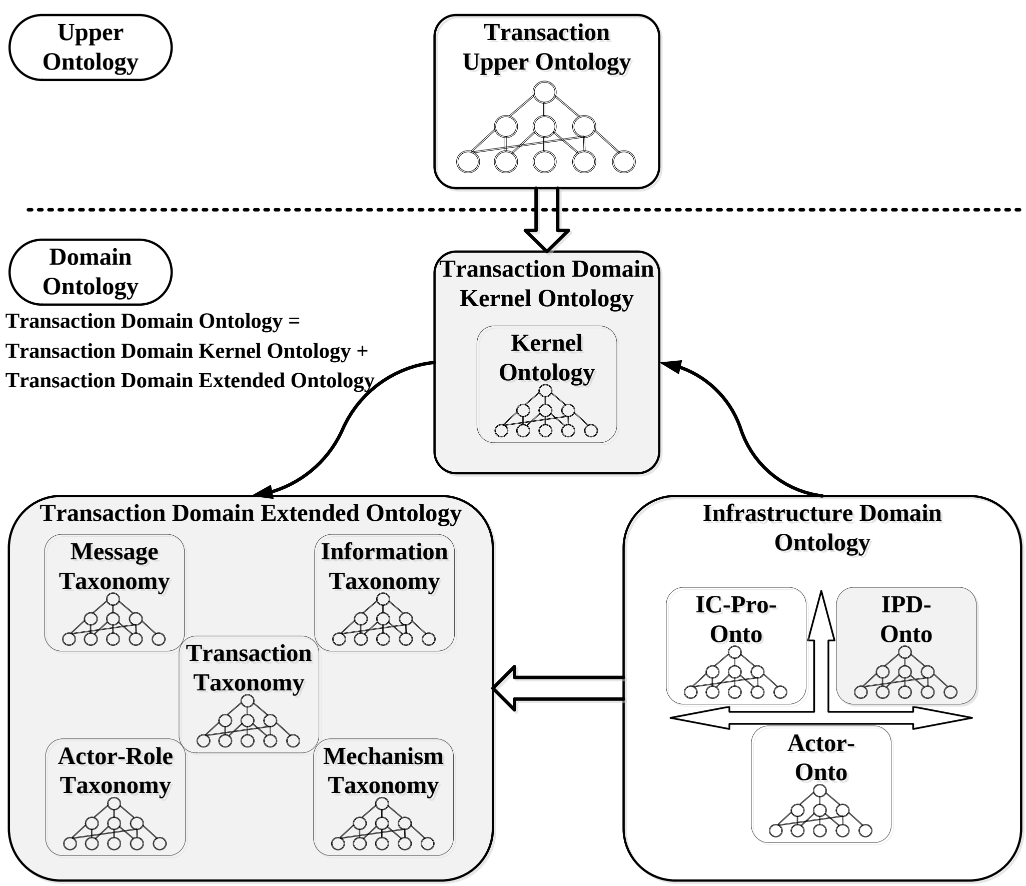


Figure 4-1 Transaction domain ontology development architecture

Defining ontologies at different levels of abstraction is a common practice in prominent ontological development approaches (El-Diraby and Kashif, 2005). According to Fensel (2001), the two benefits of defining knowledge at two distinct levels are reusability and interoperability. The transaction ontology is developed to capture transaction knowledge at the domain level so that it can be used to develop diversified applications and software systems in the area of infrastructure management. Also, the transaction knowledge captured at the domain level can also be used to formalize transactions in other application areas within the AEC/FM industry.

The Trans_Dom_Onto is developed at three levels of abstraction as shown in Figure 4-1. The highest level in the ontology architecture is the Transaction Upper Ontology (Trans_Upper_Onto) representing the most generic concepts that are same across all industries. In this research, the Trans_Upper_Onto is adapted from the upper ontologies of the previously introduced infrastructure ontologies (IPD-Onto, IC-Pro-Onto, and Actor-Onto). The Trans_Upper_Onto is organized into core and support concepts. The core concepts represent the key generic concepts that form the basis of the transaction domain knowledge, including project, action, product, and resources, and they are characterized by trans-industry generality (which means that the knowledge is so generic that it is applicable to a range of industries). The support concepts assist the modeling, organization, classification, and definition of the core concepts, including attribute, modality, mechanism, constraint, and relationship. These core and support concepts are described in detail in Zeb and Froese (2011). A brief description of the Trans_Upper_Onto is at Appendix D, Section D.1.

In the second layer, the Transaction Domain Kernel Ontology (Trans_Dom_Kernel_Onto) represents the central concepts that are extended further to develop the Trans_Dom_Extended_Onto (Trans_Dom_Extended_Onto) at the third layer. Similar to the Trans_Upper_Onto, the knowledge in the Trans_Dom_Kernel_Onto is also organized into core-concept and support-concept as shown in Figure 4-2.

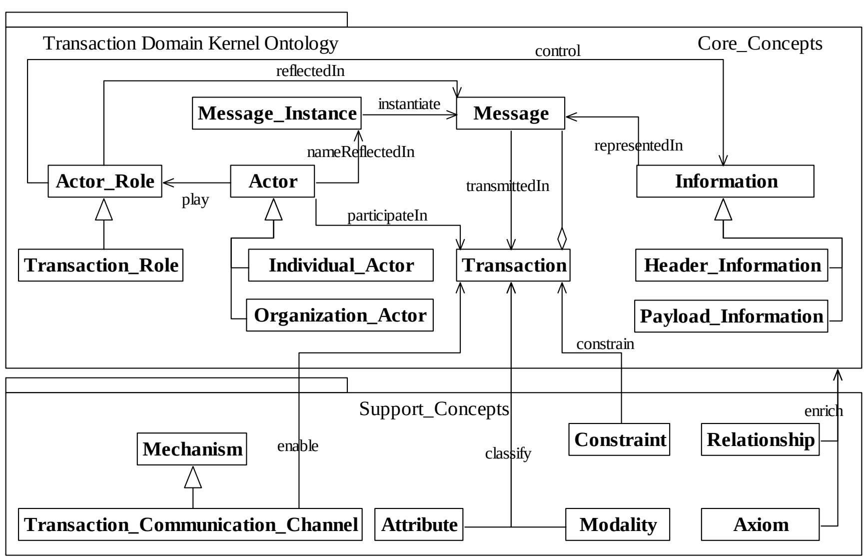


Figure 4-2 Transaction domain kernel ontology

The Trans_Dom_Kernel_Onto was described in detail in Zeb and Froese (2011) and a brief description is provided in Appendix E, Section E.1.5). The core concepts (including; transaction, message, actor, actor role, and information) and support concepts (including; attribute, modality, relationship, constraint, mechanism, and axiom) presented in the

Trans_Dom_Kernel_Onto were extended to create comprehensive taxonomies of these concepts as part of the Trans_Dom_Extended_Onto development. Except for the transaction and message taxonomies discussed in this chapter, all other taxonomies of the core and support concepts are presented in Appendix E, Section E.1.6. Moreover, the link between the Trans_Dom_Extended_Onto and the other three infrastructure ontologies (IPD-Onto, IC-Pro-Onto, and Actor-Onto) indicates that the knowledge represented in these ontologies can also be used to define transactions and messages in the domain of infrastructure management.

4.3.2 Ontology Development Methodology

A ten-step methodology was used to build the Trans_Dom_Onto, which was a hybrid version of the various methodologies developed by: (i) Fernandez-Lopez *et al.* (1997)—the METHONTOLOGY; (ii) Uschold and Gruininger (1996); and (iii) Noy and McGuinness (2001). Details can be found in Zeb and Froese (2011) and Appendix E, Section E.1; however, a brief description of each step is as follows:

i. *Step 1: define the ontology coverage*—the purpose, use, and users of the ontology are defined (Appendix E, Section E.1.1).

ii. *Step 2: capture competency questions*—a requirement analysis is made based on discussions with industry experts (i.e five experts are contaced during a colloquim and conference and an informal discussion is made) and a review of the state-of-the-art standards, methodologies, models, and ontologies (Appendix E, Section E.1.2.1). Based on the requirement analysis, a set of competency questions (CQs) is formulated, which the ontology should be able to answer (Appendix E, Section E.1.2.2).

iii. *Step 3: create/generate taxonomy*—next, a set of concepts that are required for transaction formalism are captured from state-of-the-art work process and communication standards, methodologies, and ontologies. These concepts were also discussed informally with various domain experts during an IT survey conducted as part of this research work. Core concepts (e.g. transaction, message, actor, actor role, information, etc.) are identified and a preliminary categorization is made. Synonymous concepts are identified, redundant concepts are deleted, and a preliminary taxonomy is generated (Appendix E, Section E.1.3).

iv. *Step 4: reuse existing ontologies*—to the maximum extent possible, existing ontologies are reused by establishing links between the Trans_Dom_Onto and other ontologies in the domain of infrastructure management (Appendix E, Section E.1.4).

v. *Step 5: develop Transaction Domain Kernel Ontology*—the core and support concepts related to the transaction domain knowledge are represented at an abstract level to capture a lean structure of the ontology (Appendix E, Section E.1.5).

vi. *Step 6: extend Transaction Domain Kernel Ontology*—each concept represented in the kernel ontology is extended to develop detailed taxonomies of the core and support concepts (Appendix E, Section E.1.6).

vii. *Step 7: capture ontology*—the concepts represented in the detailed taxonomies are explicitly defined using soft and hard axioms. Soft axioms are defined using plain English and hard axioms are defined in the ontology web language's (OWL) description logic syntax (DLS) (Appendix E, Section E.1.7).

viii. *Step 8: code ontology*—the ontology is formally coded in OWL using the Protégé ontology editor (Protégé, 2011) (Appendix E, Section E.1.8).

ix. *Step 9: evaluate ontology*—the knowledge in the ontology is formally evaluated (Appendix E, Section E.1.9).

x. *Step 10: document ontology*—finally, the ontology is formally documented (Appendix E, Section E.1.10).

4.3.3 Core Concept Taxonomies in the Transaction Domain Ontology

As shown in the Transaction Domain Kernel Ontology, transaction, message, actor, actor role, and information are the four core concepts that are extended to create comprehensive taxonomies as part of the Trans_Dom_Onto. This chapter focuses on the development of the transaction (Section 4.4) and the message (Section 4.5) taxonomies. The concepts captured in these taxonomies will be used to design and manage transactions and messages in the infrastructure management domain. Based on different categorization of concepts in the taxonomies, one can implement web services to manage transaction specifications and messages in terms of archiving, search, and retrieval over the web.

4.4 Transaction Taxonomy

As stated, a transaction is defined as any communication or interaction between the sender and receiver roles that results in the flow of information through a single or a sequenced set of messages. Transactions are classified based on transaction-modality, which is a "characteristic that describes a thing and denotes it's belonging to a particular group or category" (El-Gohary, 2008). A modality views a concept from one particular perspective. Transactions are categorized according to a number of modalities organized under two groupings: communication transaction-modality and domain transaction-modality, as illustrated in Figure 4-3 and Figure 4-4 respectively.

4.4.1 Communication Transaction-Modalities

The communication transaction-modalities classify communication transactions based on how they are communicated between the collaborating partners. Various categorizations of the communication transactions are as follows.

4.4.1.1 Pattern Transaction-Modality

The pattern transaction-modality classifies transactions based on the interaction patterns they follow. A pattern describes the way a single or a set of atomic transactions are arranged in a given transaction that is to be followed consistently. Any solo interaction between collaborating parties that results in the transfer of information from one party to the other is termed an atomic transaction. Pattern transactions have five sub-classes:

One action with acknowledgement transaction (pattern 1)—is composed of a single action and acknowledgement message. For instance, a general contractor (GC) communicates with a sub-contractor (SC) in relation to an interim progress payment. In this communication, the GC notifies (notification action message) the SC of the release of the progress payment. Upon receipt of the payment, the SC sends a receipt-acknowledgement message to the GC to signal confirmation of the receipt of the progress payment. In this example, there is one action (notification) and one acknowledgement (receipt confirmation) message.

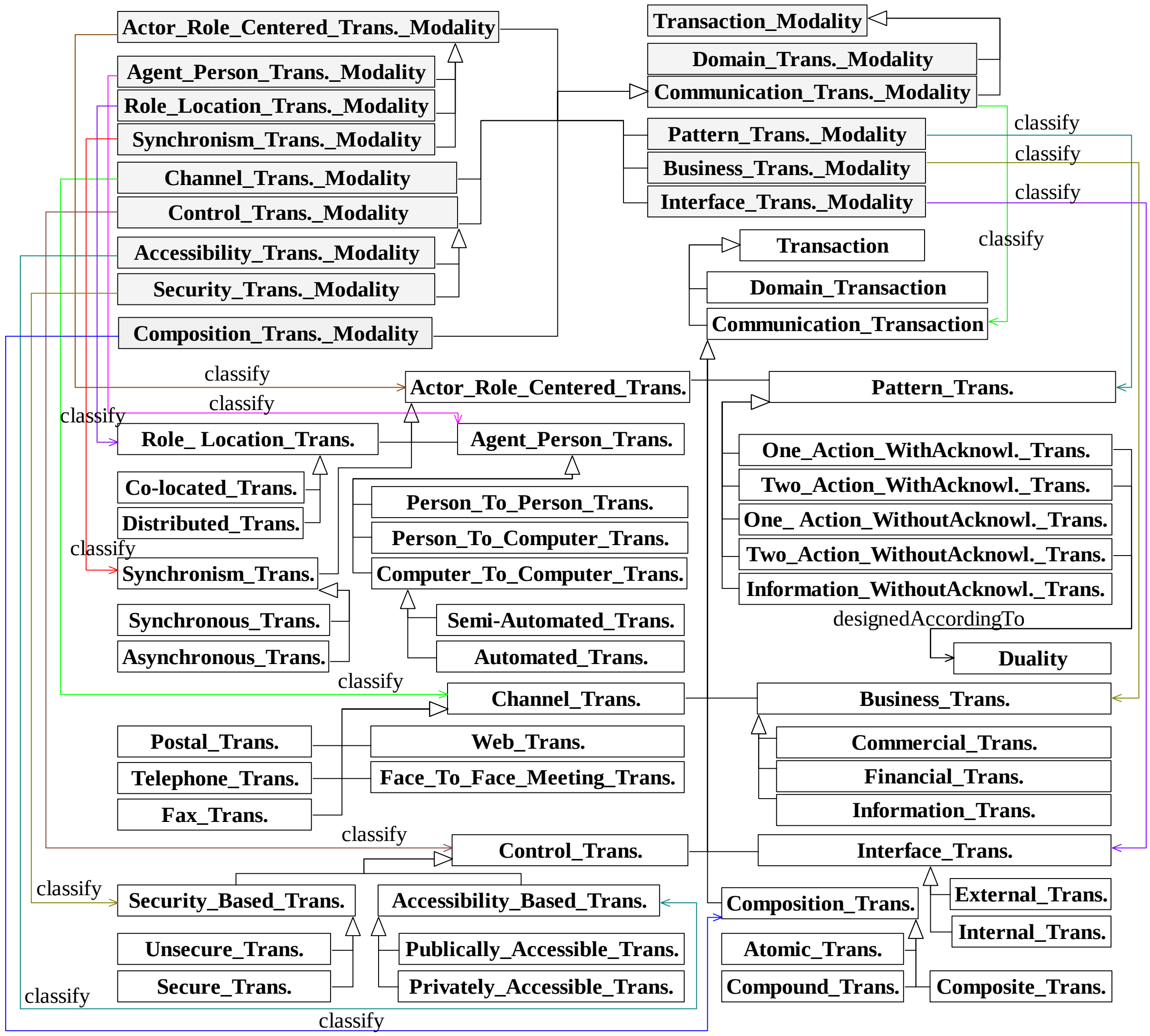


Figure 4-3 Transaction taxonomy based on communication transaction-modality

Two action with acknowledgment transaction (pattern 2)—is composed of two action and two acknowledgement messages (Dietz, 2006). For instance, a GC communicates with a SC during a bidding process, where the GC requests the SC to quote rates for some items (quote request action message). The SC receives the message and sends back a receipt-acknowledgment message to the GC to signal confirmation of the request. The SC submits the quotes (quote response action message) to the GC, who confirms receipt of the quote via a receipt-acknowledgement message. In this transaction, there are two action (quote request and quote response) and two receipt acknowledgement messages.

One action without acknowledgement transaction (pattern 3)—is composed of a single action message that is transmitted between the parties, where the sender of the message requests the receiver to carry out certain actions. No acknowledgment message is required. For instance, a municipality requests the contractor to follow best practices while locating underground assets.

Two action without acknowledgement transaction (pattern 4)—is composed of two action messages. Prevailing communication practices among partners in the AEC/FM industry, mostly follow this design pattern. For example, a construction manager (CM) communicates with a design engineer (DE) for the supply of drawings. The CM requests (request action message) the DE to supply the latest construction drawings. In response, the DE sends a copy of these drawings to the CM. In this transaction, there are two action messages: request and send action messages.

Information without acknowledgement transaction (pattern 5)—is composed of a single information message, where possession of information is transferred from the sender role to the receiver role for information dissemination only. There is no need of acknowledgement on the part of the receiving role. For instance, notifications and circulars issued by the municipality to other parties are a type of information dissemination without acknowledgement.

Moreover, in multi-action transactions where dialogues between two or more actors involve a larger number of information exchanges, these can be treated as collections of one and/or two-action patterns. Furthermore, transaction patterns 1, 2, and 4 in Figure 4-3 follow the concept of duality. According to ISO (2006), duality refers to the reciprocating behavior of parties involved in a transaction in terms of the bi-directional exchange of economic resources. In Trans_Dom_Onto, instead of economic resources, information resources are reciprocated or exchanged between the sender and receiver roles to accomplish a transaction successfully.

4.4.1.2 Business Transaction-Modality

The business transaction-modality classifies business transactions based on the type of resource being exchanged between the parties as a result of the transaction. A resource can be physical, financial or informational. A business transaction is defined as any communication or interaction between the actor roles that results in the exchange or transfer of possession of the resources from one role to the other. The terms “exchange” and “transfer” is of particular importance as they apply to certain transaction types as elaborated in the subsequent paragraphs.

Commercial transaction—is defined as any communication or interaction between the actor roles that results in the exchange or transfer of possession of money (financial resource) for products (physical resource) and services. This transaction describes buying and selling or service delivery transactions between the actor roles, where two different kinds of resources are exchanged to accomplish a transaction. For example, in a material procurement process, a municipality transfers possession of something of value (money) for the purchase of a product (material), while a vendor supplies the product in response. According to ISO (2006), the Open-edi Onto represents concepts related to the commercial transactions that are based on the concept of duality, where resources are reciprocated between the sender and receiver roles in a transaction.

Financial transaction—is any communication or interaction between the actor roles that results in the exchange or transfer of possession of financial resources. All types of bank transactions, including check, deposit, withdrawal, payment transfer-in, and transfer-out, fall under this category.

Information transaction—is any communication or interaction between the parties that results in the exchange or transfer of possession of information resources (Pouria, 2006). For instance, a contractor requests a change-order approval (information resource) from a municipality, and the municipality grants the approval (information resource) in response. This results in the exchange of information from both sides.

4.4.1.3 Interface Transaction-Modality

The interface transaction-modality categorizes transactions based on whether they are exchanging information across or within the boundaries of the organizations; that is, external and internal transactions.

External transaction—refers to the exchange of information between the actor roles from different organizations (across organizational boundaries), e.g. a municipality sends asset information to the provincial government.

Internal transaction—refers to the exchange of information between the actor roles from different departments of the same organization; e.g. engineering department sends tangible capital asset information to the accounting department.

The core focus of the Trans_Dom_Onto is to formalize external transactions. In this regard, a set of external transactions have been identified that have the greatest potential for IT improvement. One of the potential transactions to be formalized is the Asset Inventory And Condition Assessment Reporting/Tangible Capital Asset Reporting (AI&CAR/TCA) Reporting (AI&CAR/TCA) Reporting between the municipal and provincial government as explained in Section 4.7.

4.4.1.4 Composition Transaction-Modality

The composition transaction-modality classifies transactions based on their composition. It has three sub-classes.

Atomic transaction—is a solo communication between collaborating parties that results in the transfer of information from one party to the other. It is also defined as a transaction in which a conversation/dialogue between two parties is completed in a single communication.

Compound transaction—refers to a transaction in which a conversation/dialogue between two parties is completed in more than one single communication using either one action with acknowledgement or two action with/without acknowledgement transactions.

Composite transaction—refers to a transaction in which a conversation/dialogue between two or more parties is completed in more than one single communication using a set of compound transactions. It is also called a multi-action transaction.

4.4.1.5 Actor-Role-Centered Transaction-Modality

The actor–role-centered transaction-modality classifies transactions based on the interaction, location, and response timings of the actor roles. This modality has the following sub-classes:

Agent-person transaction-modality—classifies transactions based on the type of actor (either a person or a computer agent) who is sending and receiving the information. According to Anumba and Evbuomwan (1999), agent-person transactions can be person-to-person (P2P), person-to-computer (P2C), and computer-to-computer (C2C). P2P transactions include face-to-face meetings, telephone conversations, post-mail, fax, etc. P2C transactions occur when a person interacts with his/her computer system (i.e. entering data as input to the computer and receiving results as output produced by the computer. The C2C transactions can be semi-automated data exchanges, which involve some user control over the exchange of data between computer systems, or fully automated data exchanges between the electronic agents, as in the case where a user pays municipal fee through an automatic withdrawal from his/her bank. These C2C transactions are the primary focus of this research.

Role-location transaction-modality—classifies transactions based on the geographic location of the parties communicating with each other. According to Anumba and Evbuomwan (1999), it has two types: co-located transactions—where both the actor roles involved in the exchange of information are at the same place (e.g. face-to-face meetings)—and distributed transactions—where both the actor roles involved in a transaction are separated in diverse geographic locations. Transactions in the AEC/FM industry are mostly distributed due to its fragmented nature, but because of global technological advancement, parties are now virtually collocated, thus easing the problems of geographic spread.

Synchronism transaction-modality—is based on the response timings of the communication between two or more parties. According to Ashley (2003), this can be synchronous—here two or more parties communicate in real time—or asynchronous—involving time delays between each information flow among the parties.

4.4.1.6 Channel Transaction-Modality

The channel transaction-modality classifies transactions based on the modes of transmission (channels) being used for the exchange of information between parties; e.g. web transaction, face-to-face transaction, postal transaction, telephone transaction, and fax transaction (Anumba and Evbuomwan, 1999).

4.4.1.7 Control Transaction-Modality

The control transaction-modality classifies transactions based on the control imposed on the transaction transmission. It has the following two sub-classes:

Accessibility transaction-modality—classifies transactions based on accessibility to the transaction execution: either publicly accessible transactions or privately accessible transactions where only authorized personnel have access to the transaction execution.

Security transaction-modality—classifies transactions based on whether messages are exchanged via secured or unsecured networks.

4.4.2 Domain Transaction-Modalities

While the previous modalities assess the communication features of the transaction, the domain transaction-modalities classify transactions based on the civil engineering domain of the transaction. These include four modalities: collaboration, sector, project service delivery, and function process as shown in Figure 4-4.

4.4.2.1 Sector Transaction-Modality

The sector transaction-modality classifies transactions based on the infrastructure sector to which the transactions belong. The sectors for infrastructure transactions are typically one of the following: water, wastewater, gas, telecommunication, transportation, electricity, and building.

4.4.2.2 Project Service Delivery Transaction-Modality

The project service delivery transaction-modality classifies transactions based on the mode of the project service delivery. Typically, project service delivery transactions are categorized into following five project delivery modes: traditional design-bid-build; design-build; design-build-operate; design-build-operate-finance, and construction management. The Trans_Dom_Onto covers only commonly practiced project delivery modes in the AEC/FM industry. In the future, the Trans_Dom_Onto can be extended to represent other modes of service delivery. According to Yu *et al.* (2007), expandability is one of the important characteristics of ontological development. Therefore, the Trans_Dom_Onto is structured in a modular way to ease expansion of the ontology in future, if deemed to be required, by adding more modalities.

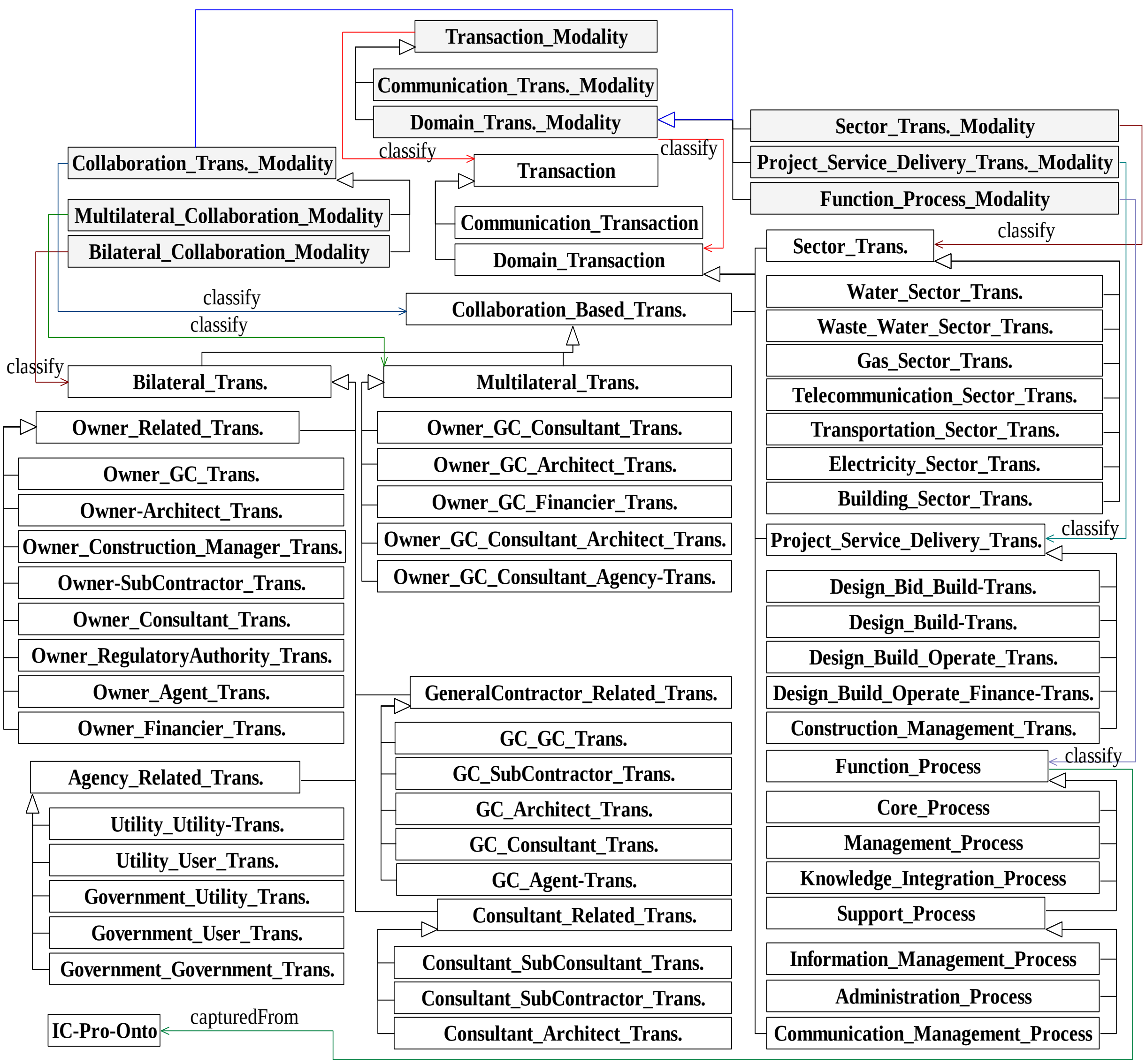


Figure 4-4 Transaction taxonomy based on domain transaction-modality

4.4.2.3 Function Process Modality

The function process modality classifies transactions based on the functional classification of processes in the project life cycle. El-Gohary (2008) classifies AEC/FM processes into four main classes based on the functions they perform: core process, management process, knowledge integration process, and support process. A transaction is an information exchange process; as such, it is classified as a support process. Although core, management and knowledge integration processes are not relevant to transactions, they are included to establish a correct linkage to the IC-Pro ontology. Administrative and information management processes are examples of support processes. Information management processes are of particular interest to our research work, as Trans_Dom_Onto will capture all such information exchange processes from the IC-Pro-Onto. These processes do not directly result in achieving project objectives, but they indirectly support key processes to achieve project goals. Successful and timely completion of projects is highly dependent on synchronizing support processes with the other three types of processes (i.e. core, management, and knowledge processes).

4.4.2.4 Collaboration Transaction-Modality

In collaborations, two or more parties interact with each other to exchange information. The collaboration transaction-modality classifies transactions based on the number of parties involved in a transaction. It has two types: bilateral and multilateral collaboration transaction-modality.

The bilateral collaboration transaction-modality categorizes transactions that are taking place between two parties. It has three sub-classes: owner-related transaction, consultant-related transaction, agency-related transaction (agency refers to a government agency), and general contractor-related transaction. The multilateral collaboration transaction-modality is used to classify transactions involving three or more parties. Collaboration-based transaction classification is not exhaustive; it can easily be extended if required.

4.5 Message Taxonomy

In this research, an approach is adopted to formally describe and specify a transaction (transaction specification) in terms of three elements: the transaction map showing the flow of information, the actor roles involved in the transaction, and the information represented in the form of a message. Thus, the message makes up one component of a transaction. A transaction message refers to the information in tangible (written) and intangible (verbal) forms that is exchanged between the parties in a given transaction.

As an integral part of a transaction, the message captures both the content (payload) and context (header) information that is required to be exchanged in a transaction. The content information is the actual data content that the parties require to exchange to complete various tasks. The context information represents the meta-data required to recognize, identify, and represent actual data content sent and received between the parties. For instance, a municipality sends an E-mail to the consultants requesting them to submit asset condition assessment information. In this example, the E-mail addresses of sender and receiver roles, subject of the E-mail, and the date E-mail sent is the context information, whereas the actual request in the form of textual information is the content information.

The message modality classifies messages based on: (i) the function it performs in a transaction; (ii) how information is formulated in a message; (iii) how information is represented in a message, and (iv) the level of interpretational capabilities built into the message. Therefore, the message modality is classified into function, formulation, representation, and intelligent modalities as represented in Figure 4-5.

4.5.1 Function Modality

The function modality classifies messages based on the functions these messages perform in a transaction. Three functions have been identified to be performed by a message; they are: requesting a party to perform some action, disseminating information, and sending a signal to collaborating partners.

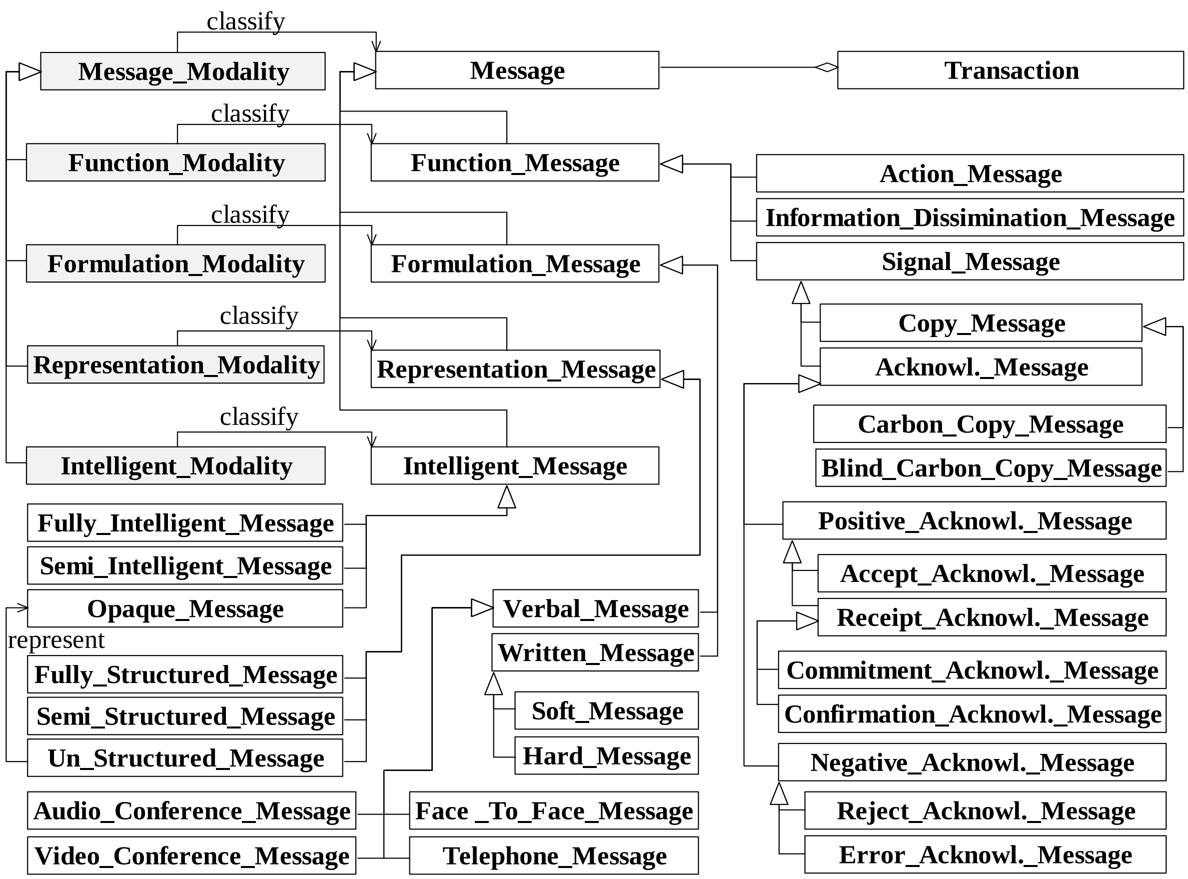


Figure 4-5 Message taxonomy

Function messages have the following three sub-classes, which are explained with the aid of an example as shown in Figure 4-6. In the example, a pavement structural design engineer requests a project maintenance manager to submit pavement condition assessment information, who forwards the request to a road inspector to carry out the road inspection and submit the road assessment information. The road inspector completes the road inspection and submits the information to the project maintenance manager, who then forwards it to the pavement structural design engineer. This transaction follows a two action with-acknowledgement design pattern.

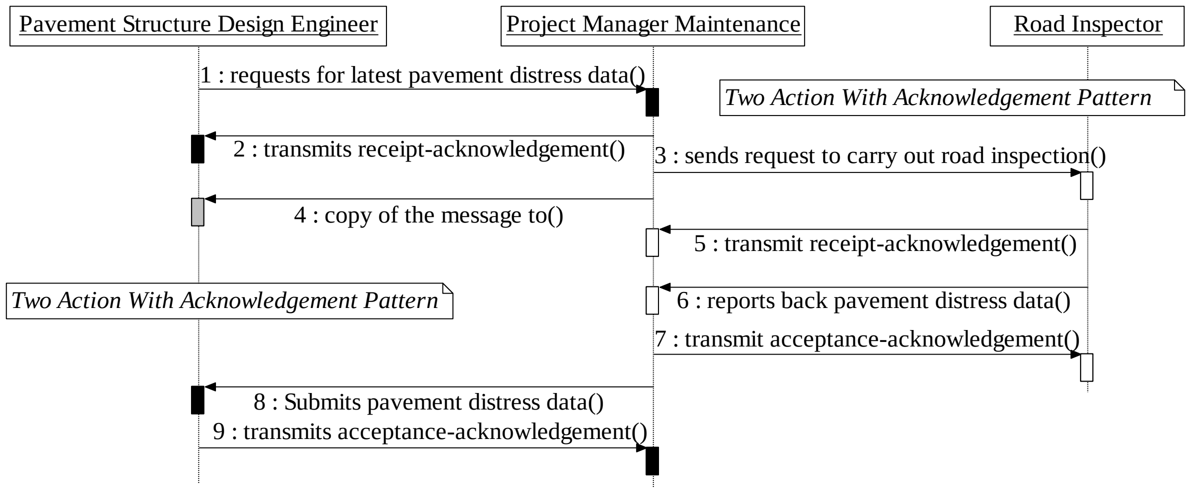


Figure 4-6 Transaction showing various messages

Action message—is a message that contains information pertaining to the execution of an action, or reporting the accomplishment of an action in a given transaction. According to Damodaran (2004), the business document exchanged between the roles during the business activities is called an action message. Actions include: request, report, submit, approve, etc. Examples of action messages are demonstrated via messages 1, 3, 6 and 8 in Figure 4-6.

Information dissemination message—is a message that performs the function of distributing information to other parties. This message does not require a recipient party to perform an action or acknowledgement. Examples are notification and circular.

Signal message—is a message representing information that is related to the act of admitting, accepting, confirming, and informing a receiver role. In other words, a signal message is used to acknowledge (e.g. acknowledgement message) or inform a receiving role on the progress of any action that is requested through an action message (e.g. carbon copy, blind carbon copy message). A signal message has two types: copy and acknowledgment message. A copy message is used where one or more parties are "carbon copied" or "blind carbon copied" on the action messages. These copies are considered to be signal messages since the receiving party is not expected to perform any action. Acknowledgement messages contain information that relates to the recognition of the validity of the action message. Acknowledgement messages can be positive (receipt-acknowledgement messages—messages 2 and 5 in Figure 4-6 or accept-acknowledgment messages—messages 7 and 9 in Figure 4-6), or negative (reject-acknowledgment messages or error-acknowledgement messages).

4.5.2 Formulation Modality

The formulation modality classifies messages based on the mode of message creation that is verbal or written messages. Sub-classes of verbal message are audio and video conference, telephone, and face-to-face meeting. Written messages have two types: soft messages—formulated using electronic means—and hard messages—formulated using non-electronic means.

4.5.3 Representation Modality

The representation modality classifies messages based on the degree to which information is structured.

Fully structured message—is the one in which the header and payload information is fully structured in terms of description and format. A fully structured message is like a template that can be instantiated in transactions time and again through giving values to the structured data fields.

Semi-structured message—according to Pustejovsky and Feinman (1997), a semi-structured message contains a known set of fields, but with some of the fields containing unstructured text or other information. Also, a fully structured message with textual or image file attached is a semi-structured message. For instance, E-mail is a semi-structured message in which the structure and format of some fields (date, E-mail address) are completely defined, whereas the E-mail message body is completely unstructured and free to allow a sizable information in any form.

Unstructured message—is one in which information is represented in a completely loose, unrestricted, and free style format. For example, a letter written in electronic or non-electronic means in a style that is independent of any compositional (format) and structural restrictions.

4.5.4 Intelligent Modality

Intelligent modality classifies messages based on the interpretational capabilities of the computer systems that send and receive the message. Intelligent messages are of three types: fully intelligent, semi-intelligent, and opaque.

Fully intelligent message—contains fully structured information that is semantically and syntactically interpretable by the computers. Semantic interpretational capabilities can be achieved through developing ontologies. A knowledge-enabled fully structured template is an example of this message.

Semi-intelligent message—contains semi-structured information that is partially interpretable by computers. For instance, information in an E-mail body is unstructured and captured in a format that is not computer interpretable.

Opaque or static message—contains complete unstructured information that is totally not interpretable by the computer. For instance, a letter compiled in a word processor falls into this category.

4.6 Ontology Evaluation

There are three main approaches to ontology evaluation: gold standard evaluation (Dellschaft and Staab, 2008), task-based evaluation (Yu *et al.* 2007), and criteria-based evaluation (Gomez-Perez, 2001). The gold standard approach compares the candidate ontology with an existing ontology that is considered to be the standard in a specific domain. This approach is used to select an ontology from a set of existing ontologies that is directly applicable to the domain of interest. This approach is not applicable to this research as the goal of this work is to evaluate the content of the ontology from the perspective of a specific domain. The task-based approach evaluates a candidate ontology based on its competency to accomplish certain tasks. The task relates to whether the ontology implements an application. Therefore, the performance of the ontology is judged from the perspective of a specific application context. This approach is feasible for the evaluation of a candidate application ontology where the focus is on one specific application, whereas it is not applicable to evaluate a domain ontology like the Trans_Dom_Onto. The criteria-based approach evaluates a candidate ontology according to some criteria or frame of reference. This approach is the most applicable to evaluate the content of a domain ontology as the focus of a domain ontology is not on a specific task/application or user, but rather it represents the knowledge at the domain level that can be used to develop various application and user ontologies and applications.

According to Gomez-Perez (2001), evaluation involves judging the content of the ontology with respect to some frame of reference, such as a set of requirements (Appendix E, Section E.1.2.1), competency questions (Appendix E, Section E.1.2.2) (defined as ontology verification) and the real-world model of the domain (defined as ontology validation). The Trans_Dom_Onto verification has been completed using automated Protégé reasoners and competency questions, whereas ontology validation was completed using expert interviews. The Trans_Dom_Onto evaluation framework is presented in Appendix E, Section E.1.9, Table E-2.

The proposed criteria to evaluate the Trans_Dom_Onto include consistency, conciseness, completeness (Gomez-Perez, 1996), correctness (Guarino, 1998), and clarity (Gruber, 1995 and Yu *et al.* 2007). According to Gomez-Perez (1996), the definitions of consistency, conciseness, and completeness along with their measures are as follows. *Consistency* measures the level to which the concepts represented in the ontology are consistent, i.e. contradictory conclusions cannot be drawn from the definitions of these concepts. Consistency is measured using three types of errors: circulatory errors, partition errors, and semantic inconsistency errors. Circulatory errors occur when a class is defined as a sub-class or super-class of itself. Partition errors occur when disjointedness between various classes in the taxonomy is omitted or not properly defined. Semantic inconsistency errors occur when a class declaration is semantically inconsistent with the context of the class hierarchy. *Conciseness* measures the level to which the concepts represented in the ontology are concise, i.e. no redundant concepts are represented in the ontology. Conciseness is measured using grammatical redundancy errors. Grammatical redundancy errors occur when more than one relationship is defined between the same generalization-specialization classes. *Completeness* measures the level to which the knowledge represented in the ontology is complete. According to Yu *et al.* (2007), there are no measures developed yet to prove completeness of an ontology, rather it can be demonstrated in terms of incompleteness. According to Guarino (1998), *correctness* measure the level to which the knowledge represented in the ontology is accurately modeled from the real world perspective. Identity errors measure the correctness of the knowledge representation in terms of semantic compliance with the WorldNet or real-world context. According to Gruber (1995), *clarity* measures the level to which a knowledge representation is clear and understandable. Class description communication errors measure the clarity of a knowledge representation. The class description communication errors occur when a concept declaration is not clear and understandable resulting in ineffective communication of the intended meaning of the defined classes of concepts.

Verification tools used to satisfy these aforementioned criteria include automated description logic reasoners in Protégé 4.0.2, such as FaCT^{++}, Pallet, and RacerPro 2 (Protégé, 2011), and competency questions. These reasoners are run to automatically check the content of the ontology for consistency (in terms of circulatory and partition errors) and conciseness (in terms of grammatical redundancy errors). The reasoning analysis shows that the Trans_Dom_Onto is consistent and concise (Appendix E, Section E.1.9.1, Figure E-20 (a, b, and c).

Competency question-based verification involves evaluating the content of the ontology based on the competency questions developed as part of the ontology development, which the ontology has to answer. The set of CQs that relates to the communication transaction-modality includes: (i) Are transactions designed based on different design patterns? (ii) Are transactions defined based on the exchange of the physical, financial, and information resources? (iii) Is a transaction defined based on whether it is external or internal to the organization? (iv) Is a transaction formalized based on the location of transaction roles? (v) Are transactions defined based on the flow of information between persons and computer agents? (vi) Are transactions designed based on the response timings? (vii) Are transactions defined based on the means of transmission? (viii) Does transaction design incorporate control over transaction accessibility? (ix) Does transaction design incorporate transaction security?

The set of CQs pertains to the domain transaction-modality includes: (i) Are transactions designed and grouped according to bi-lateral and multi-lateral collaboration? (ii) Are transactions defined based on the sector or application area? (iii) Does transaction design incorporate different modes of the project delivery as a governing factor for the design of transactions? and (iv) Does the Trans_Dom_Onto reflect the support processes defined in the IC-Pro-Onto?

The CQs for message modality include: (i) Are messages defined based on the function they perform in an information exchange scenario? (ii) Are messages classified based on whether they are formulated as verbal or written messages? (iii) Does a message design incorporate how information is to be represented in a message? and (iv) Does a message design incorporate the level to which the information represented in the message is computer interpretable?

Each of these competency questions was checked manually and the percentage compliance with measures (including; semantic inconsistency errors, incomplete concept classification, and identity errors) was determined (Appendix E, Section E.1.9.2). The percentage compliance for each type of measure is the sum of CQs in error divided by the total number of CQs multiplied by 100. The compliance of each measure (in terms of the errors found in the concept description), was recorded as full-compliance (denoted as F, which means a CQ is error free for a specific measure), partial-compliance (denoted as P, which means a CQ is partially erroneous, i.e. in between the two extremes for a specific measure), and non-compliance (denoted as N, which means a CQ is fully erroneous for a specific measure). The results of the competency question-based verification indicate that the ontology was 100% free of semantic inconsistency error. Moreover, for incomplete concept classification errors, 79% of the classes found to be error-free while 21% had partial errors. In addition, competency questions were verified for identity errors and found to be 79% error-free, 19% partial errors, and 2% errors (Appendix E, Section E.1.9.2, Table E-3).

The ontology was modified accordingly to address errors in the ontology. For circulatory and partition errors (i.e. consistency checks), and grammatical redundancy errors (i.e. conciseness check), Protégé automated reasoners were re-run until all reported errors were corrected. Moreover, the ontology was revised to address semantic inconsistency errors (consistency check), incomplete concept classification (completeness check), and identity errors (correctness check). As the Trans_Dom_Onto is an extended version of the Trans_Kernel_Dom_Onto, these evaluation results also apply to the Trans_Kernel_Dom_Onto. These results show satisfactory compliance with competency questions.

The ontology was validated through three domain experts using a structured interview approach. Each of them had more than 15 years of experience in different civil engineering fields. They were extremely familiar with the transportation sector while moderately familiar with the water, wastewater, and solid waste management sector. In addition, they were moderately familiar with the data or information modeling and the process of communication formalization. A structured questionnaire (see Appendix C), was presented to the respondents/interviewees wherein questions were organized according to three assessment criteria: clarity, completeness, and correctness. For each question, a multi-sheet table was developed to reflect various concepts in rows and respondents' responses in the columns. The respondents were asked to rate a given concept on a scale of 1 (strongly disagree) to 5 (strongly agree) in each of the three assessment criteria. The responses were recorded for each concept reflected in the tables developed for clarity (Appendix E, Table E-6), completeness (Appendix E, Table E-8), and correctness (Appendix E, Table E-10), and an average score was calculated. The average score ranged from 4 (agree) to 5 (strongly agree), which indicates that all the respondents were in universal agreement on the clarity, completeness, and correctness of the knowledge represented in the Trans_Dom_Onto.

The validation data were also analyzed for statistical significance using ANOVA two-factor without replication technique. An alpha factor of 0.05 or 95% confidence level was used in the statistical analysis. The statistical analysis was conducted to either accept or reject the null hypothesis, which states that there is no statistical significance between the responses of various respondents. The results of the analysis shows that the value of "F" is less "Fcri" ($F<Fcri$), and the value of "p" is greater than the alpha factor (0.05) for all the three criterion: clarity (Appendix E, Table E-7), completeness (Appendix E, Table E-9), and correctness (Appendix E, Table E-11), This indicates that there is no statistical significance and the null hypothesis is to be accepted, which means that the respondents are in universal agreement on the clarity, completeness, and correctness of the knowledge represented in the Trans_Dom_Onto.

An overall ontology validation assessment was conducted as shown in Appendix E, Table E-12. The overall average rating of the Trans_Dom_Onto was 4.67 on a scale of 5 shows that the results are satisfactory and the respondents are in full agreement on the clarity, completeness, and correctness of the knowledge represented in the ontology.

4.7 Application of the Transaction Domain Ontology

The research intent is to apply the Trans_Dom_Onto to formalize a set of transactions and messages in the infrastructure sector that have the greatest potential for IT improvement. In this regard, a set of transactions was identified during an IT survey conducted as part of this research work. One of the potential transactions identified in the domain of municipal infrastructure management is the reporting process between municipalities and the provincial government for the exchange of asset inventory and condition assessment/tangible capital asset information. There are three issues associated with this process as it is currently practiced. *First,* the asset information is exchanged as an E-mail attachment in the form of an electronic report created in Microsoft Word or PDF formats. These reports need human interpretation at the receiving end, making the whole process prone to errors. *Second,* the provincial government receives several different types of asset information reports from different city, district, town, and village municipalities, making it more difficult and time-consuming to extract and compile data from these different reports manually. *Third,* different municipalities use different information systems to manage their infrastructure systems. These systems support different information models and; therefore, create and send data in different formats. The reports generated from various municipalities differ in the definition and grouping of the assets into different categories.

The heterogeneity of information hampers standardization efforts that lead to message-based interoperability between information systems of the infrastructure organizations.

This research proposes that these issues could be addressed through the development of an Asset Information Integrator System, AIIS (discussed in Chapter 9), at the provincial government level that will receive, read, and integrate the asset inventory and condition assessment/tangible capital asset information received from various municipalities through standardized message templates. This will result in a message-based interoperability between the information systems of these agencies.

For information systems of these agencies to talk to each other, the need is to formalize the flow of information, specify actor roles, and define the messages (referred to as message templates) in a computer interpretable format—i.e. based on an ontology. Therefore, the Trans_Dom_Onto was developed as part of this research work to support the design of information flows and message templates in the domain of infrastructure management. The knowledge represented in the Trans_Dom_Onto is to be used to formalize the communication process and define the message templates that are exchanged between the municipal and provincial government as part of the Asset Inventory And Condition Assessment Reporting/Tangible Capital Asset Reporting (AI&CAR/TCA) Reporting. The AIIS is to be developed as part of this research work that will make use of these specifications to ensure consistent and structured exchange of asset information. As messages are defined in a computer interpretable format, the AIIS at the provincial level automatically receives, reads, and integrates the asset information received from various municipalities, resulting in a message-based interoperability between information systems of the infrastructure organizations. In addition, human interpretation of the asset information at the receiving end is eliminated, resulting in considerable time-savings and reduction of errors that result from extracting asset information manually from multiple heterogeneous electronic AI&CAR/TCA Reports received from municipalities.

4.8 Conclusion

The Trans_Dom_Onto is developed in the infrastructure sector of the AEC/FM industry to support the formalism of communication processes (transactions). The Trans_Dom_Onto is created at three levels of abstraction: Trans_Upper_Onto, Trans_Dom_Kernel_Onto, and Trans_Dom_Extended_Onto. Taxonomies of core concepts (transaction, message, actor role, and information), and support concepts (attribute, modality, mechanism, constraint, relationship, and axiom) are developed and relationships between the concepts are established to represent the transaction domain knowledge in the area of infrastructure management. The concepts in the ontology are captured from a number of state-of-the-art methodologies, standards, and articles. The Trans_Dom_Onto is verified using the Protégé automated reasoners and competency questions, whereas validation of the Trans_Dom_Onto is completed through expert review as part of the evaluation process. The Trans_Dom_Onto will be applied to a set of transactions in the domain of infrastructure management that have the greatest potential for IT improvement. The next step in this ongoing research work is to develop transaction specification and message templates for the AI&CAR/TCA Reporting identified during the expert interview survey. The AIIS is to be developed as part of this research that will make use of these specifications for the exchange of asset information between the municipal and provincial government.

Chapter 5 Tangible Capital Asset Ontology

5.1 Introduction

This chapter[5] is composed of eight sections that describe the development, application, and evaluation of the Tangible Capital Asset Ontology (TCA_Onto)—Objective 2 (b) in the domain of infrastructure management. The TCA_Onto represents the Tangible Capital Asset (TCA) knowledge in the four infrastructure sectors (including; transportation, water, wastewater, and solid waste management sectors) and facility sector. The knowledge in the TCA_Onto was organized according to four perspectives (modalities): individual, function, composition, and sector asset modality. The TCA_Onto was used to formalize message templates (MTs) for the Asset Inventory and Condition Assessment Reporting/Tangible Capital Asset Reporting (AI&CAR/TCA) Reporting between the municipal and provincial government. The formalized MTs were then implemented in a prototype Asset Information Integrator System (AIIS) discussed in Chapter 9. In addition, the chapter discusses the TCA_Onto evaluation using the five criteria: consistency, conciseness, completeness, correctness, and clarity.

5.2 Relevant Research Work in the Domain of Infrastructure Management

The TCA_Onto was developed based on the review of the state-of-the-art ontologies in the AEC/FM and other industries to support the design of message templates for the AI&CAR/TCA Reporting in the domain of infrastructure management. In the AEC/FM industry, the primary references underlying the development of the TCA_Onto include:

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[5] A version of this chapter is published in the proceedings of the Canadian Society for Civil Engineering Annual Conference, 2013. This chapter presents an updated and expanded version of the conference paper that is accepted for publication. In addition, some of this material is accepted as a book chapter in a monograph on ontologies in Architecture, Engineering, and Construction to be published by the American Society of Civil Engineers (ASCE).

Zeb, J. and Froese, T. (2013). "Tangible Capital Asset Ontology Towards Standardized Reporting in Infrastructure Management", 4th Construction Specialty Conference, Canadian Society of Civil Engineering, May 29-June 1, 2013, Montreal, Quebec, pp. CON-090-1~10. The focus of this paper is on the development, application, and verification of the Tangible Capital Asset Kernel Ontology in the domain of infrastructure management.

Zeb, J. and Froese, T. (2014). "Tangible Capital Asset Ontology in Infrastructure Management", Infrastructure Asset Management Journal, Vol. 1, Issue 3, Institution of Civil Engineers, ICE Publishing, United Kingdom, pp. 81-92 . The focus of this paper is on the development, application, and evaluation of the Tangible Capital Asset Ontology (including the Tangible Capital Asset Kernel Ontology) in the domain of infrastructure management.

Zeb, J. and Froese, T. (2014). "Transaction Formalization in the Infrastructure Management Using an Ontological Approach", Chapter Accepted for Publication in the Book Titled "Ontology in the AEC domain: A Decade of Research and Developments.", American Societyof Civil Engineers, USA. The book chapter captures a holistic view of the knowledge represented in the Trans_Dom_Onto and TCA_Onto, to show how the knowledge represented in these ontologies supports the design, management, and implementation of transactions in infrastructure management.

the Infrastructure Product Ontology, IPD-Onto (Osman, 2007); Infrastructure and Construction Process Ontology, IC-Pro-Onto (El-Gohary, 2008), Actor Ontology, Actor-Onto (Zhang and El-Diraby, 2009); and Transaction Domain Ontolgoy, Trans_Dom_Onto (Zeb and Froese, 2012). The TCA_Onto is an extended version of the IPD-Onto (Osman, 2007). In other related fields, the Open-electronic Data Interchange Transaction Ontology, Open-edi Onto (ISO, 2006) and Resource-Event-Agent Ontology (Allen and March, 2006) was of particular importance that led to the development of the TCA_Onto. These references are analyzed in detail to identify gaps and presented in the Chapter 1, Section 1.4.3.

5.3 Methodology to Develop Tangible Capital Asset Ontology, (TCA_Onto)

An eleven-step methodology was formulated to build the TCA_Onto. This methodology was devised based on a number of existing approaches developed by: (i) Gruninger and Fox (1995); (ii) Uschold and Gruininger (1996); (iii) Fernandez-Lopez *et al.* (1997); and (iv) Noy and McGuinness (2001). A brief description of each step follows.

Step 1: identify motivating scenario—to build the TCA_Onto, a motivating scenario was identified by identifying a set of transactions that have the greatest potential for IT improvement. In this research work, the AI&CAR/TCA Reporting transaction was identified for IT improvement during an IT survey conducted as part of this research work.

Step 2: define ontology coverage—this step defines the purpose, usability, and scope of the TCA_Onto. The *purpose* of the TCA_Onto was to represent the TCA knowledge explicitly and unambiguously to address three issues: TCA data heterogeneity, lack of consistency in the TCA class descriptions, and lack of component-wise aggregation of TCAs. The *usability* refers to the uses of the TCA_Onto. In this research work, the TCA_Onto was used to create consistent MTs for the AI&CAR/TCA Reporting for further implementation in the AIIS. The *scope* of the TCA_Onto was to represent the TCA knowledge within the domain of facility management and infrastructure management sectors: transportation, water, wastewater, and solid waste management.

Step 3: capture competency questions (CQs)—according to Gruninger and Fox (1995), competency questions (CQs) are a set of questions that the ontology should be able to answer. The CQs, then, provide a representation of the *ontology's requirements*. For the TCA_Onto, the following five requirements were identified. The TCA_Onto should represent; (i) the TCAs within the four infrastructure sectors: transportation, water, wastewater, and solid waste management; (ii) the notion of hierarchical classification of the TCAs, i.e. generalization-specialization; (iii) the composition-aggregation relationships of the TCAs; (iv) the attributes and modalities of the TCAs; and (v) the relationships among diverse TCAs. For each requirement, CQs were developed as discussed in the evaluation section.

Step 4: generate preliminary taxonomy—a preliminary taxonomy of the core TCAs was developed using a 4C approach: capture, compare, categorize, and create/generate. The TCA knowledge was captured from the literature, reports, and expert's tacit knowledge, which was then compared to remove synonymous concepts. A preliminary categorization of the TCAs was made based on different modalities that led to the creation of a preliminary, modality-based taxonomy for the TCAs.

Step 5: reuse and merge existing ontology—where possible, existing relevant ontologies should be reused while developing a new ontology. To develop the TCA_Onto, the existing IPD-Onto was extended to produce the TCA_Onto in the domain of infrastructure management.

Step 6: develop tangible capital asset kernel ontology—the TCA_Kernel_Onto was developed first to model four modalities of the TCAs at a high level of abstraction. These modalities are: individual, function, composition, and sector asset modalities. The purpose of developing a kernel ontology was to capture a lean structure to represent a holistic view of the TCA knowledge, enhance comprehension, ease concept extensions, ease concept navigation, and better organize the TCA knowledge.

Step 7: extend tangible capital asset kernel ontology—the sector asset modality represented in the TCA_Kernel_Onto was further specialized and extended to develop the TCA_Extended_Onto to represent detailed taxonomies of different TCAs. The generalization-specialization, aggregation-composition, and association relationships were used to represent and define the TCA knowledge explicitly.

Step 8: capture ontology—means the development of the soft and hard axioms. An *axiom* describes a concept unambiguously and places constraints on its interpretation (Osman, 2007). *Soft axioms* define a concept in plain English, whereas *hard axioms* describe it in a formal language like the ontology web language (OWL). Soft axioms and three types of hard axioms were defined for the TCA_Onto: sub-sumption, disjoint, and property-restriction.

Step 9: code ontology—means representing the knowledge in a formal language. The TCA_Onto was formally coded using the Protégé ontology editor. The OWL was used due to its richness, robustness, and wide-spread acceptance.

Step 10: evaluate ontology—involves assessing the content of the ontology with respect to a frame of reference (Gomez-Perez, 1996). The purpose of the TCA_Onto evaluation was to determine if the knowledge model of the TCAs was developed correctly (verification) and if the correct knowledge model was developed (validation). The complete description of the TCA_Onto evalution is presented in the evaluation section of this chapter.

Step 11: document ontology—involves writing-up the knowledge so that is can be reused in the future. The TCA_Onto development concluded with documenting the model to support future re-use.

5.4 Development of a Modality-based Tangible Capital Asset Kernel Ontology

The TCA_Kernel_Onto represents a modality-based view of TCA knowledge at an abstract level as shown in Figure 5-1. According to El-Gohary (2008), modality defines “the characteristics of a concept and denotes its belonging to a particular group or category." The TCA modality is a meta-modality that classifies the TCAs based on four perspectives (modalities). The concepts represented in Figure 5-1 using boxes with a gray background are adopted from the IPD-Onto developed by Osman (2007). A brief description of each modality is as follows.

5.4.1 Individual Asset Modality

The *individual asset modality* classifies the TCAs based on the type of the individual asset. According to PSAB (2009) and TCA (2012), individual asset has eight sub-classes: land, land improvement, building, building improvement, infrastructure, machinery and equipment, vehicle, and work in progress.

5.4.2 Function Asset Modality

The *function asset modality* categorizes the TCAs based on the function they perform in the overall infrastructure system. According to Osman (2007), there are six such functions: control, access, protection, measuring, storage and conveyance assets. Two additional functions were added as part of this research work: commuting and processing.

5.4.3 Composition Asset Modality

The *composition asset modality* defines the TCAs based on their aggregation level in the overall infrastructure system. From Osman (2007), these can be: system, sub-system, and component level. For example, in a water supply system, the distribution network is a system level asset, a water line is a sub-system level asset, and an individual valve is a component-level asset.

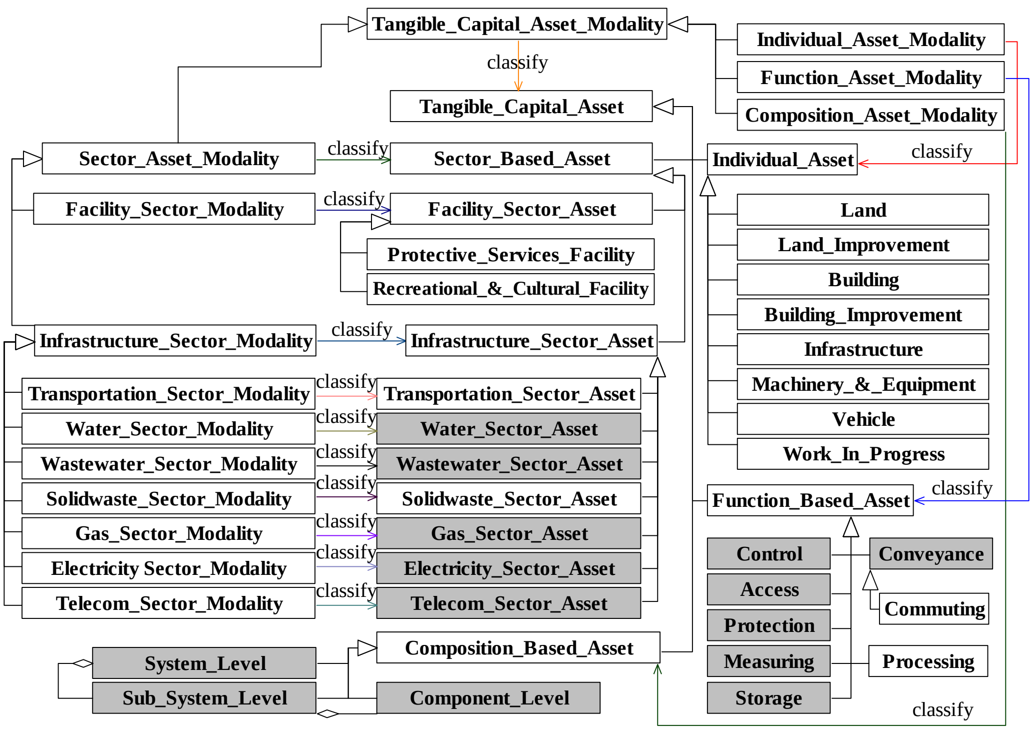

Figure 5-1 Modality-based tangible capital asset kernel ontology

5.4.4 Sector Asset Modality

The *sector asset modality* categorizes the TCAs based on the infrastructure domain or sector in which they are used. The sector asset modality is further decomposed into two sub-classes: *facility sector modality*—classifies TCAs based on facility type, and *infrastructure sector modality*—categorizes TCAs based on their type of discrete and linear infrastructure. The infrastructure sector modality has seven sub-classes: transportation, water, wastewater, solid waste management, gas, electricity, and telecom sector modalities. Both the facility and infrastructure sector modalities were further specialized and extended to develop detailed taxonomies of different facilities and infrastructure assets within the transportation, water, wastewater, and solid waste management sectors. The modality-based classification or taxonomies of the gas, electricity, and telecom sector assets were omitted as these assets are generally not owned and operated by municipal infrastructure organizations.

5.5 Development of a Modality-based Tangible Capital Asset Ontology

The TCA_Onto was developed at two levels of abstraction: TCA_Kernel_Onto and TCA_Extended_Onto. The *TCA_Kernel_Onto* represents the TCAs at a very abstract level, which are specialized to develop the TCA_Extended_Onto. The specialization of the TCA_Kernel_Onto's abstract concepts into much more detail was to provide a specific data model to support the TCA information systems. The TCA_Extended_Onto employed the four modalities defined in the TCA_Kernel_Onto as well as refining some of these modalities further. The TCA_Extended_Onto organized the TCAs according to the individual asset modality (land, land improvement, building, building improvement, infrastructure, machinery and equipment, vehicle, and work-in–progress asset types). This allows assets to be easily identified, managed, and reported by their asset type. Furthermore, the TCA_Extended_Onto built upon the TCA_Kernel_Onto's sector asset modality and refined this with significant detail. The refinements to the facility sector modality are described in Section 5.5.1 and the extensions to the infrastructure sector modality are discussed in Section 5.5.2.

5.5.1 Facility Sector Modality

The TCA_Extended_Onto uses the sector asset modality to categorize assets into either facility sector types or infrastructure sector types. The first of these, *facility sector modality,* classifies the types of facilities that exist in the AEC/FM industry as shown in Figure 5-2.

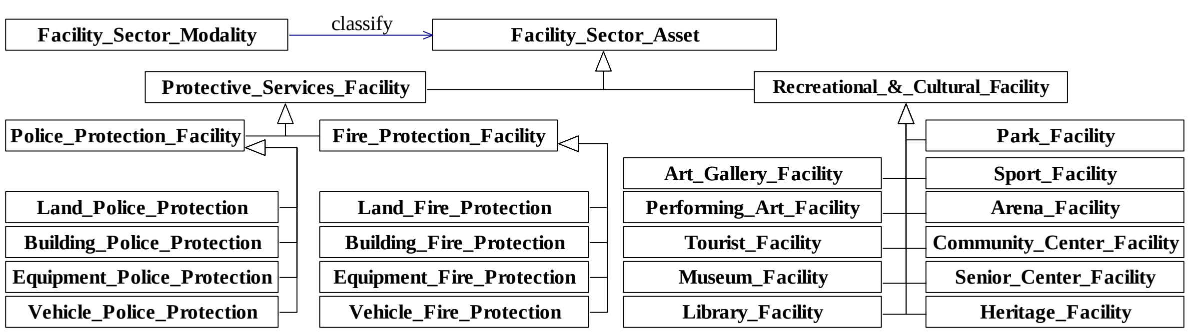

Figure 5-2 Modality-based taxonomy of the facility sector assets

5.5.2 Infrastructure Sector Modality

The second major category of sector asset types is represented by the infrastructure sector modality. The sub-types of infrastructure types that are refined within the TCA_Extended_Onto, described in the following sections, include transportation sector assets, water sector assets, wastewater sector assets, and solid waste sector assets.

5.5.2.1 Transportation Sector Modality

The *transportation sector modality* classifies transportation sector assets in 14 main categories as shown in Figure 5-3: road, bridge, tunnel, pathway, shoulder, wall, curb, median, street light, guard rail, land, building, machinery and equipment, and vehicle transportation assets. The road and bridge transportation assets were further categorized based on two modalities: road asset modality and bridge asset modality.

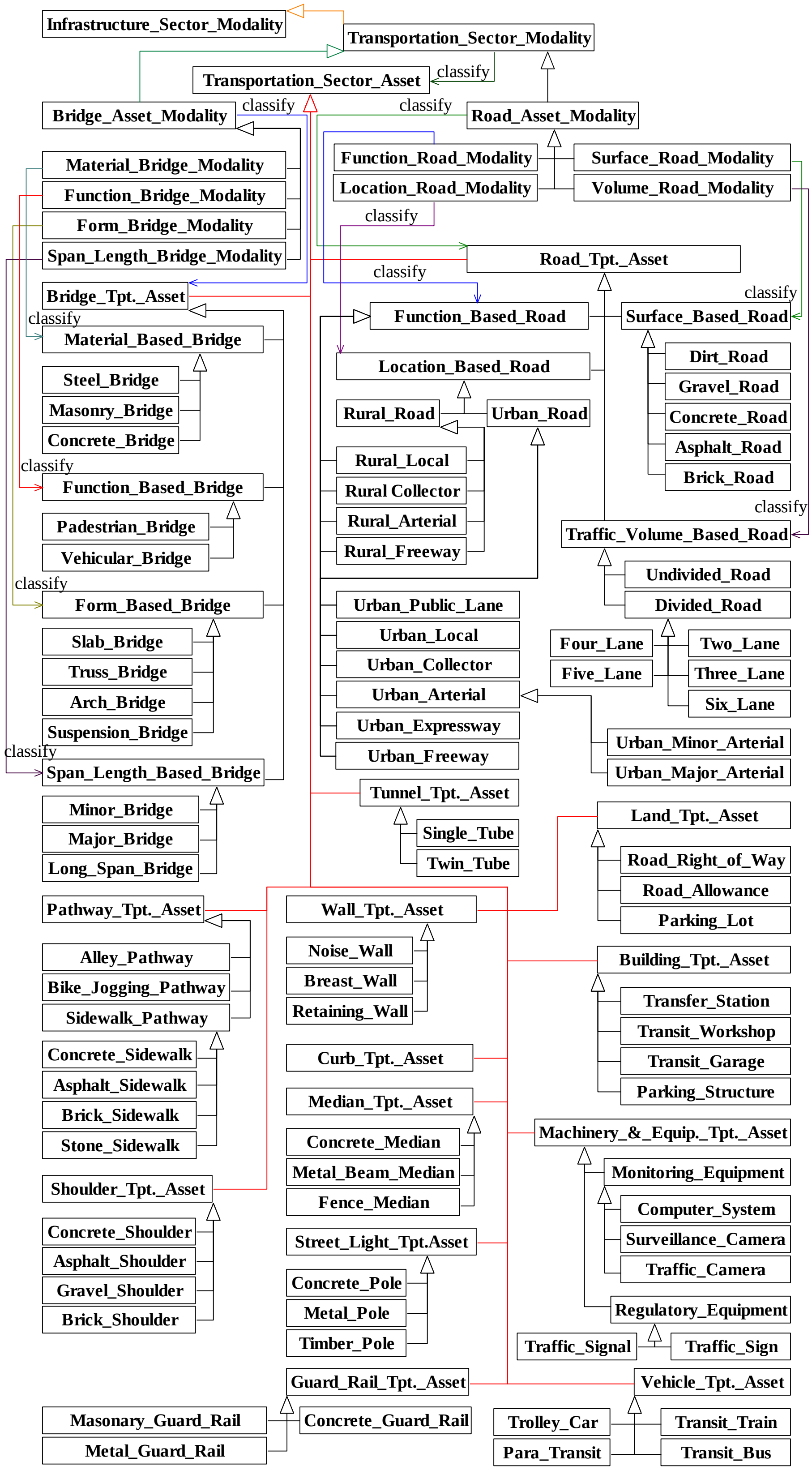

Figure 5-3 Taxonomy of the transportation sector assets

5.5.2.1.1 Road Asset Modality

The *road asset modality* classifies road transportation assets based on the function they perform in a road network; the location of roads in relation to the adjacent land use; the material with which road surfaces are constructed; and the traffic volume that the roads carry. It has the following four types.

Function road modality—classifies road transportation assets based on the function that the road performs in a road network. The function-based road classification is further associated with the location-based classification, as follows.

Location road modality—classifies road transportation assets based on adjacent land use, i.e. whether the road is passing through a rural or urban area. According to AASHTO (2011), it has two types: rural roads (passing through rural areas with population<5,000) and urban roads (passing through urban areas with population ≥5,000). The rural and urban roads were further classified based on the function road modality. According to TAC (1999), a rural road has four sub-classes—local, collector, arterial, and freeway—while an urban road has six sub-classes—public lane, local, collector, arterial, expressway, and freeway. Each of the sub-classes of the rural and urban roads are defined based on six factors: service function, land service, traffic volume, flow characteristics, design and average speed as shown in Figure 5-4 and Figure 5-5 respectively.

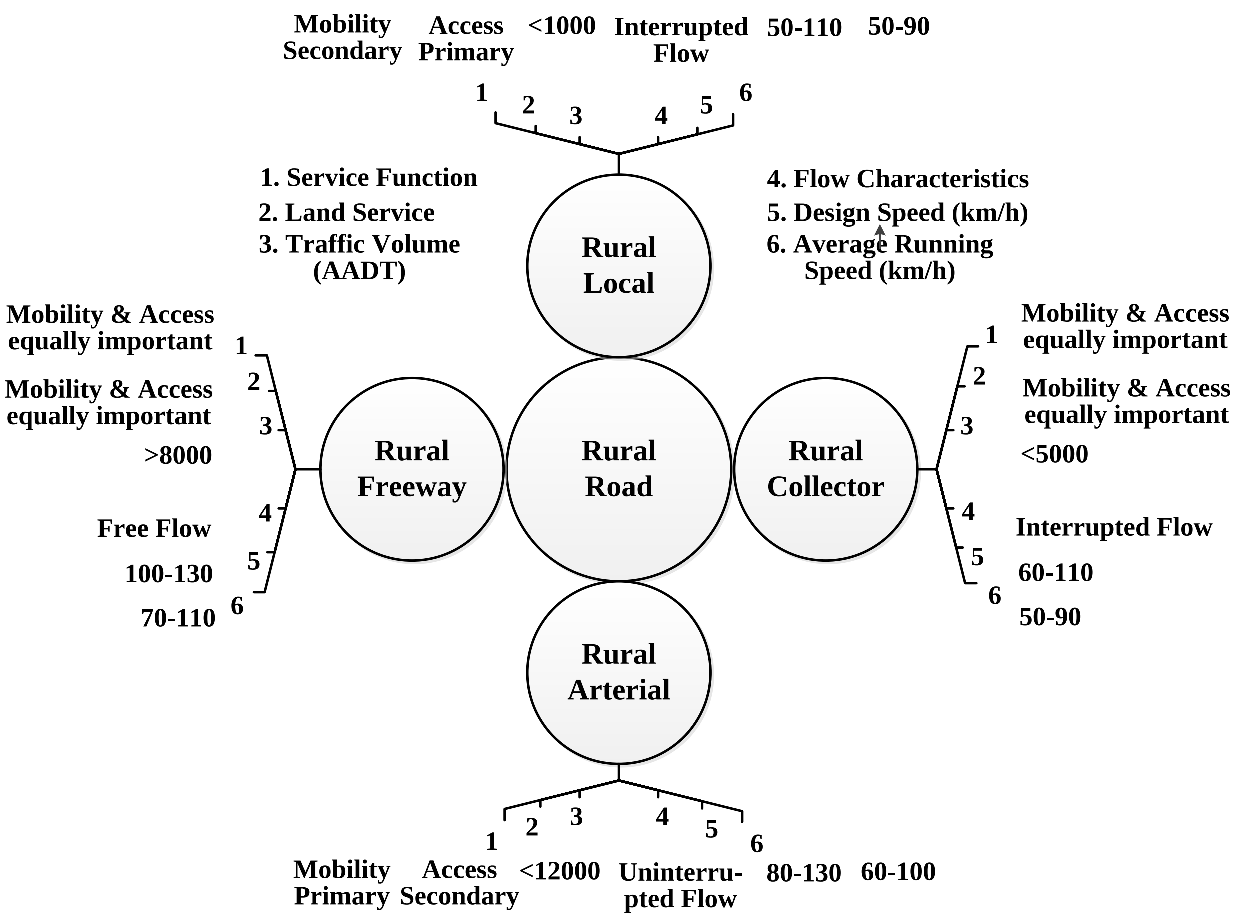

Figure 5-4 Definition of different types of rural roads

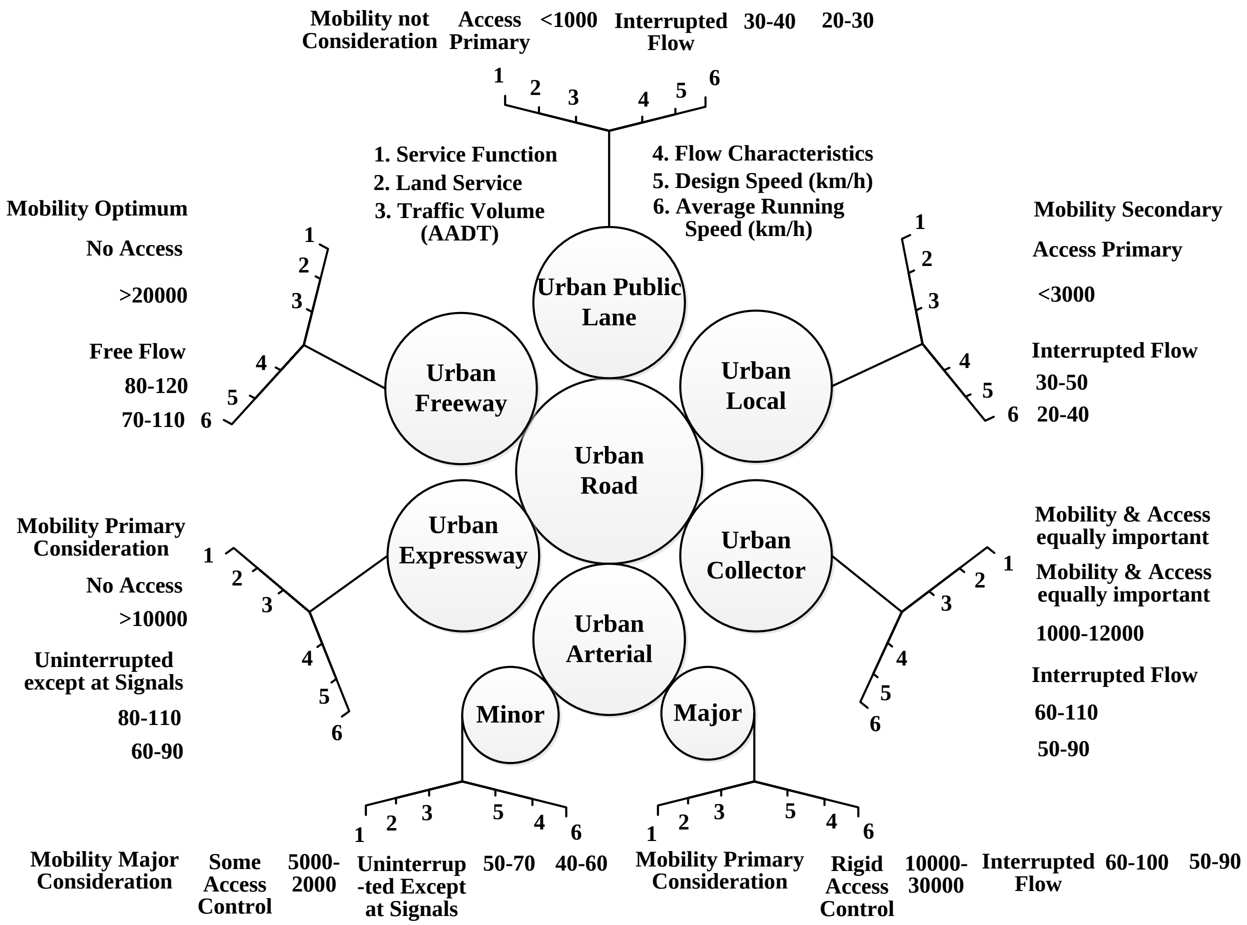

Figure 5-5 Definition of different types of urban roads

Surface road modality—categorizes road transportation assets based on the surface material used: dirt, gravel, concrete, asphalt, brick, or composite (AASHTO, 2011).

Volume road modality—characterizes road transportation assets based on road's lane and traffic flow characteristics. Based on AASHTO (2011), values can be undivided road asset (carrying bi-directional flow of traffic) or divided road asset (carrying the uni-directional flow of traffic), which is further divided according to the number of traffic lanes.

5.5.2.1.2 Bridge Asset Modality

The *bridge asset modality* classifies bridge-related assets based on four different perspectives: the construction material used, the bridge function performed, the bridge shape or form, and the span length. According to Ponnuswami (2008), definitions of different types of bridges are as follows.

Material bridge modality—classifies bridge transportation assets based on the primary construction material used: steel, masonry, or concrete.

Function bridge modality—classifies bridge transportation assets based on their function; in particular, pedestrian bridge or vehicular bridge.

Form bridge modality—classifies bridge transportation assets based on the shape of the bridge superstructure: slab, truss, arch, or suspension bridge.

Span length bridge modality—categorizes bridge transportation assets based on the bridge span length. It has three sub-classes: major bridge (>30≤120 m), minor (>6≤30 m), and long span bridge (>120m). A structure with less than a 6 m span length is said to be a culvert.

Other transportation assets that were defined in the TCA_Onto include: tunnel, pathway, shoulder, wall, curb, median, street light, guard rail, land, building, machinery and equipment, and vehicle transportation assets.

5.5.2.2 Water Sector Modality,

The *water sector modality* is a sub-class of the infrastructure sector modality that classifies water sector assets into eight main categories as shown in Figure 5-6: water line, tank, valve chamber, well, reservoir, land, building, and machinery and equipment assets. The water sector assets shown in Figure 5-6 with a gray background were adopted from the IPD-Onto (Osman, 2007). The *water line modality* further classifies water line assets based on the hierarchical water line modality and material water line modality.

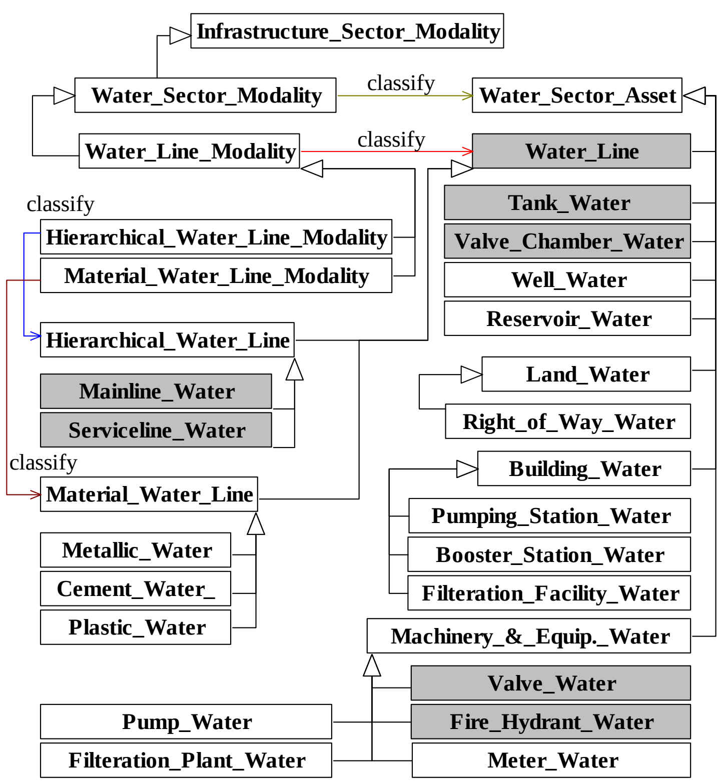

Figure 5-6 Taxonomy of the water sector assets

5.5.2.2.1 Hierarchical Water line Modality

The *hierarchical water line modality* classifies water line assets based on the hierarchical function that the water line performs in a pipe network system. According to Osman (2007), a water line has two types: main line and service line. A *mainline* is the primary pipeline (called a primary feeder or water main) used to convey water from the purification and treatment plants to the pumping stations, reservoirs, water tanks and to the ultimate consumers. A *service line* is the secondary and tertiary distribution network that transports water to the end consumers.

5.5.2.2.2 Material Water line Modality

The *material water line modality* classifies water line asset based on the material with which a pipeline is made. The material based water line asset has the following three sub-classes: (i) metallic water line asset (e.g. Cast Iron-CI, Galvanized Iron -GI, Galvanized Steel-GS, and Steel-S); (ii) cement water line asset (e.g. Asbestos Cement-AC and Concrete Cement-CS); and (iii) plastic water line asset (e.g. Polyvinyl Chloride-PVC, Chlorinated Polyvinyl Chloride-CPVC, High Density Polyethylene-HDPE, and Polyethylene-PE.

Moreover, other water sector assets that were defined in the TCA_Onto include the tank, valve chamber, reservoir, land, building, and machinery and equipment.

5.5.2.3 Wastewater Sector Modality

The wastewater sector modality is a sub-class of the infrastructure sector modality that classifies wastewater asset based on two perspectives: sanitary wastewater modality and storm wastewater modality as shown in Figure 5-7.

5.5.2.3.1 Sanitary Wastewater Modality

The *sanitary wastewater modality* classifies sanitary wastewater assets into six main classes: sanitary wastewater line, manhole, tank, land, building, and machinery and equipment as shown in Figure 5-7. The sanitary wastewater line modality has the following two types.

Hierarchical wastewater line modality—classifies wastewater line asset based on the hierarchical function a sanitary wastewater line performs in a sewerage network. It has two sub-classes: main line and service line sanitary wastewater asset (sewer). The *main line* is the trunk sewer having larger diameter that collects sewage from the secondary and tertiary sewer network in a sewerage system. The *service line* is the secondary and tertiary sewer network in the overall sewerage system.

Material wastewater line modality—classifies sanitary wastewater line asset based on the material from which the sewer is made. The material-based wastewater line asset (sewer) has three sub-classes: (i) metallic wastewater line asset (e.g. Ductile Iron-DI, Cast Iron-CI, Corrugated Aluminium-CI, and Galvanized Steel-GS sewer); (ii) cement wastewater line asset (e.g. Vitrified Clay-VC, Asbestos Cement-AC and Concrete Cement sewer); and (iii) plastic wastewater line asset (e.g. Polyvinyl Chloride-PVC, Acrylonitrile Butadiene Styrene-ABS, Reinforced Plastic Mortar-RPM, Polyethylene-PE, Polypropylene-PP, and High Density Polyethylene-HDPE sewer).

Moreover, other sanitary wastewater assets like manhole, tank, land, building, and machinery and equipment were explicitly defined in the TCA_Onto.

5.5.2.3.2 Storm Wastewater Modality

The *storm wastewater modality* is a subclass of wastewater sector modality that classifies storm wastewater assets into eight sub-classes as shown in Figure 5-7: storm wastewater line, culvert, dam, pond, dyke, land, building, and machinery and equipment. The storm wastewater line and culvert wastewater assets were further categorized based on two modalities: storm wastewater line modality and culvert wastewater line modality.

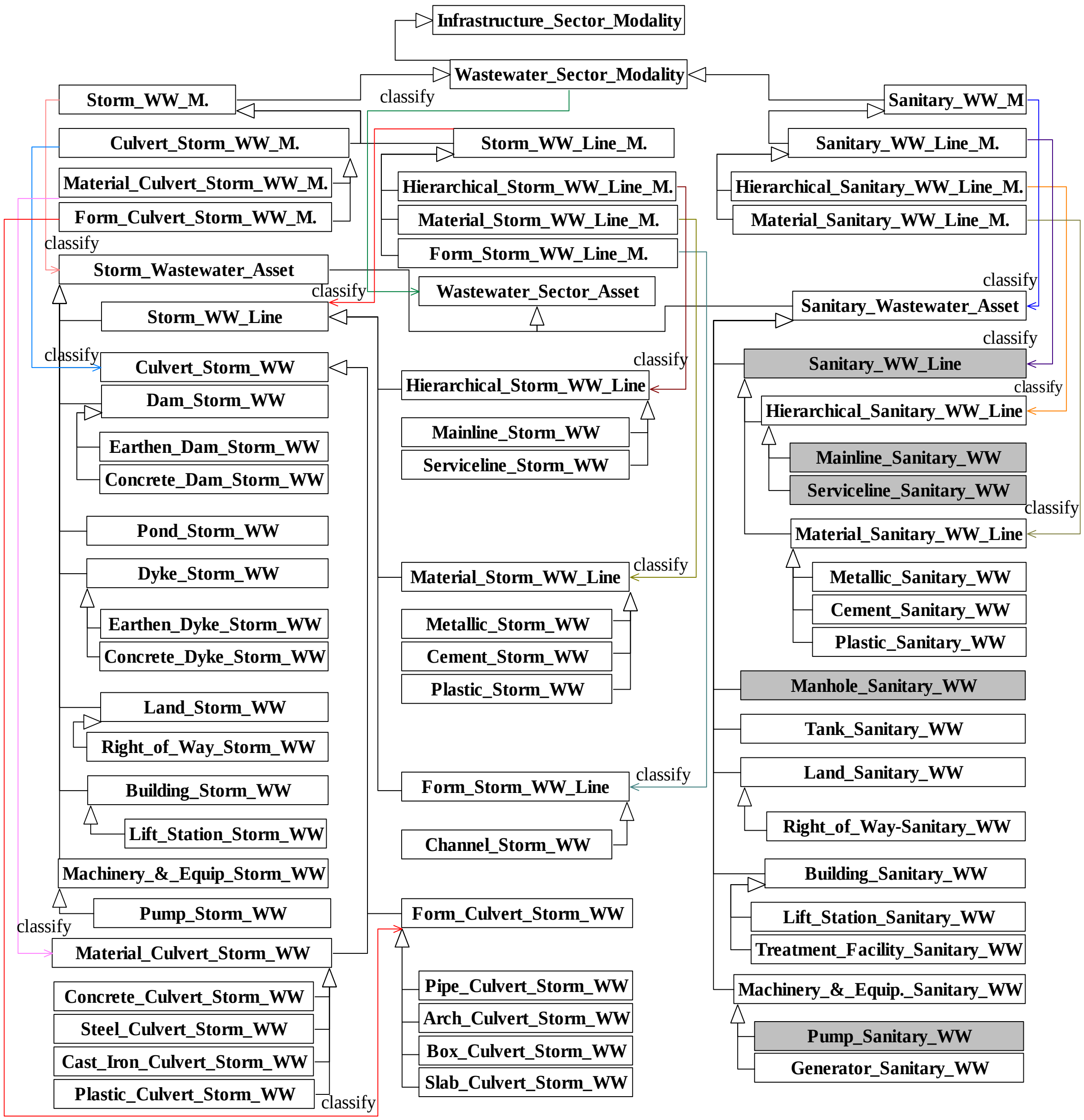

Figure 5-7 Taxonomy of wastewater sector assets

Storm wastewater line modality—classifies storm wastewater line assets based on their hierarchical function, material, and form or shape. It has the following three sub-classes. (i) The *hierarchical storm wastewater line modality* classifies wastewater lines (storm sewers) based on the hierarchical function that it performs in the overall sewerage system. It has two sub-classes: main line and service line. The *main line* is a primary or a trunk storm sewer that collects storm water from the secondary and tertiary storm sewers. The *service line* refers to the secondary and tertiary storm sewer network in the sewerage system. (ii) The *material storm wastewater line modality* classifies storm sewers based on their material. It has three sub-classes of metallic, cement, and plastic material. (iii) The *form storm wastewater line modality* classifies storm wastewater line assets based on their shape. It includes storm wastewater channel.

Culvert storm wastewater modality—categorizes culvert assets based on their material and shape. (i) *Material culvert storm wastewater modality*—classifies culvert assets based on their material: concrete, steel, cast iron, or plastic. (ii) *Form culvert storm wastewater modality*—categorizes culverts based on their shape: pipe, arch, box, or slab culvert.

Other classes of storm wastewater assets are: dam, pond, dyke, land, building, and machinery and equipment, which were also explicitly defined in the TCA_Onto.

5.5.2.4 Solid waste Sector Modality

The *solid waste sector modality* is a sub-class of the infrastructure sector modality that classifies solid waste sector assets into four main categories: land, building, machinery and equipment, and vehicles, as shown in Figure 5-8.

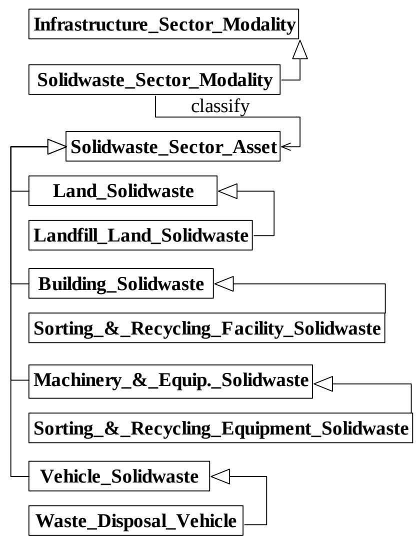

Figure 5-8 Taxonomy of solid waste sector assets

5.5.3 Tangible Capital Asset Attribute

The TCA_Onto defines asset attributes as shown in Figure 5-9. According to Osman (2007), an attribute is a characteristic that describes a thing or entity (e.g. an infrastructure product). The IPD_Onto (Osman, 2007) defines attributes of the infrastructure products and organizes them according to six modalities: physical, perception, domain, change, composition, and phase modalities. These attributes are: cost, dimension, performance, state of operation, dependency, impact, redundancy, spatial, shape, and material (all shown in Figure 5-9 with a gray background). As part of this research work, three additional asset attributes—condition, quantitative, and life—were added. The cost attribute was further extended to support the design of MTs for AI&CAR/TCA Reporting.

Condition attribute—represents the state of an asset at a specific time. According to Felio (2012), the condition of an asset is measured from two perspectives: physical condition and capacity condition, which are both further classified as very good, good, fair, poor or very poor conditions. The definitions of these terms vary with the types of assets, the acceptable levels of service set by an organization is based on its financial and social consideration, the limits of risk tolerance, and other standards. The condition index represents the overall condition based on the physical condition and capacity condition of an asset. The *condition index* is the average of the weighted averages of the physical and capacity conditions of an asset. *Quantitative attribute*—represents the quantity of an asset in the inventory of an infrastructure organization. It has two sub-classes: quantity and disposed quantity. *Life attribute*—represents the average life, remaining life, and year of installation of an asset. *Cost attribute*—represents different costs associated with an asset. It has three sub-classes: acquisition, net book value, and replacement cost.

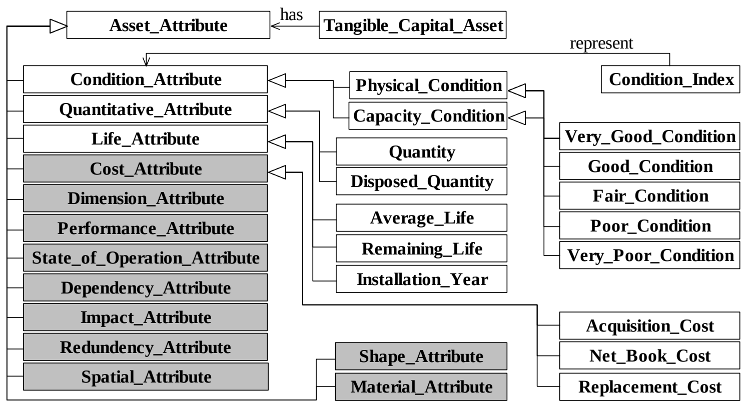

Figure 5-9 Taxonomy of tangible capital asset attributes

5.6 Application of the Tangible Capital Asset Ontology

The TCA_Onto was used to formalize message templates for the AI&CAR/TCA Reporting that was identified as one of the transactions that has the greatest potential for IT improvement. In this transaction, different municipalities report their asset inventory and condition assessment information to the provincial government for financial planning and budget allocation. Currently, this transaction is conducted on a manual and *ad hoc* basis due to the heterogeneity of the TCA data compiled in PDF or word formats. The human interpretation of the asset inventory and condition assessment data at the receiver end is time-consuming and prone to errors. The TCA_Onto was developed to formalize the AI&CAR/TCA Reporting, specifically the message templates, to transform manual reporting to a more formalized computer-to-computer based exchange of information using the prototype AIIS developed as part of this research. The message templates defined for the AI&CAR/TCA Reporting represents two types of information: header and payload information as shown in Figure 5-10 and Figure 5-11 respectively.

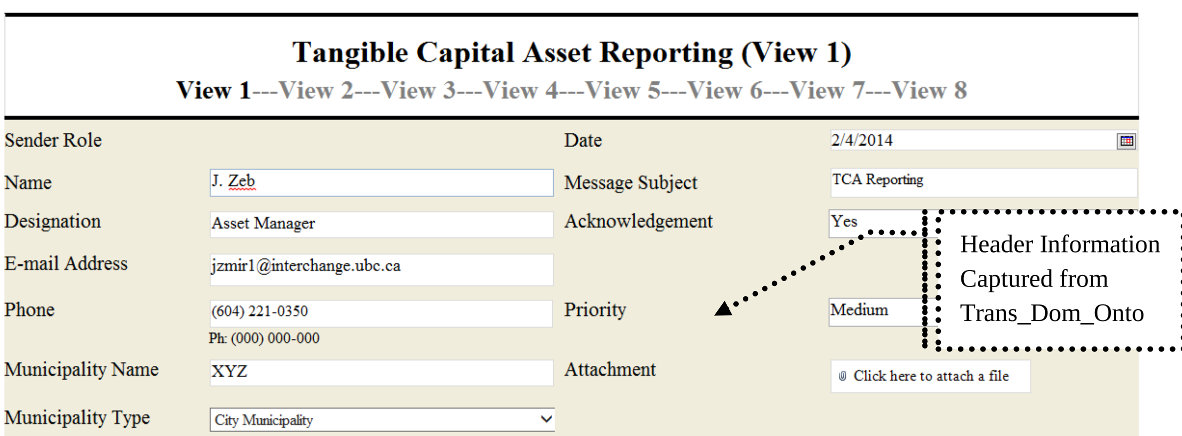

Figure 5-10 Message template header information for the AI&CAR/TCA reporting

The *header information* is the meta-information about the message template, transaction, and actor or actor role as shown in Figure 5-10. The header information was captured from the Trans_Dom_Onto developed as part of this research. The header information was represented once in a multiple view message template defined for the AI&CAR/TCA Reporting.

The *payload information* is the actual information content that the actor roles need to exchange to accomplish a transaction successfully. The payload information was captured from the TCA_Onto as shown in Figure 5-11.

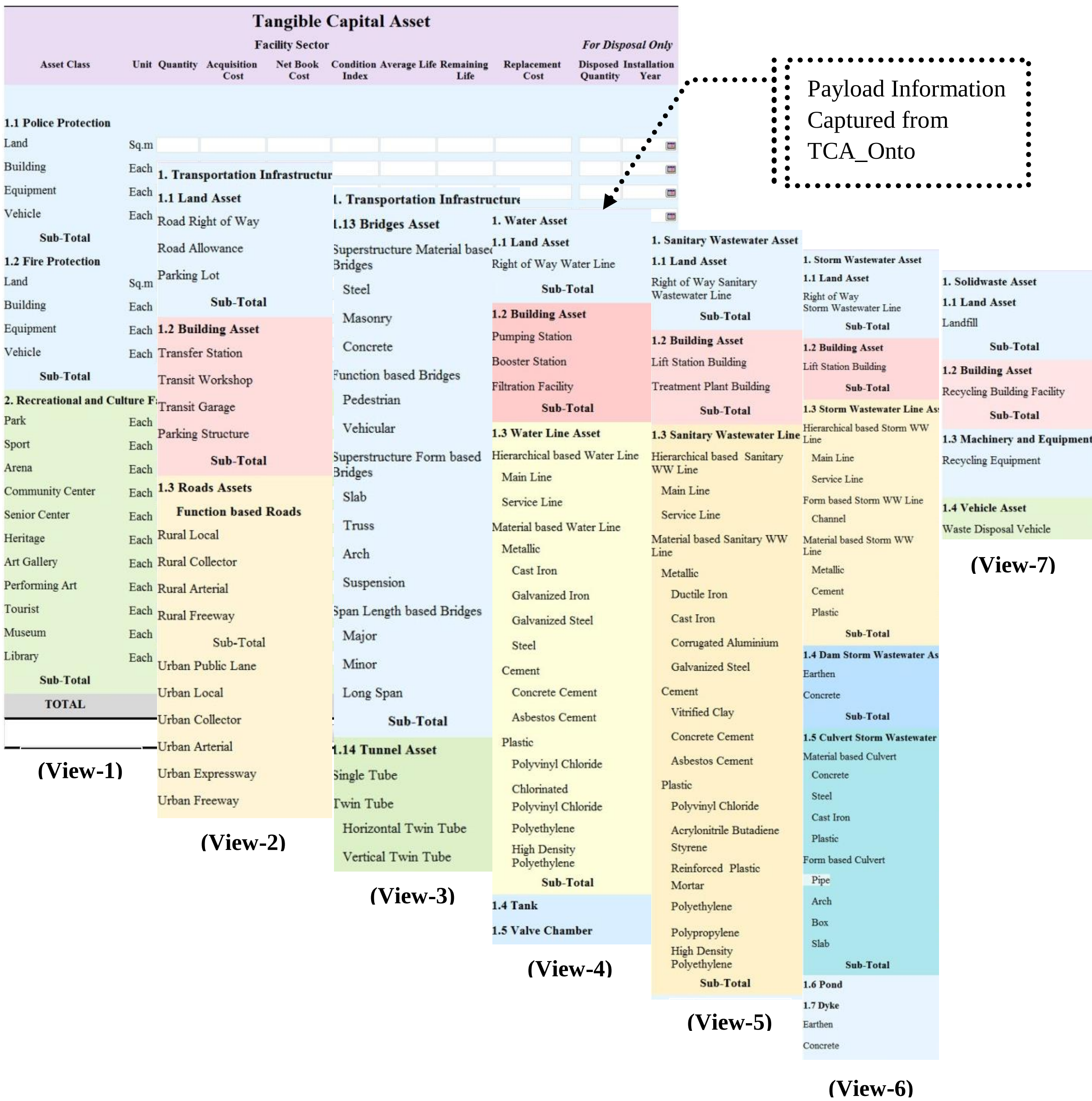

Figure 5-11 Multiple view message template showing payload information for the AI&CAR/TCA reporting

The list of the payload information (i.e. asset inventory and condition assessment) was too long to be represented in a single view; therefore, it was organized into multiple views for better management of the asset data and ease of navigation. A message template view is a web-based interface representing part of the overall payload information.

One of the message templates defined for the AI&CAR/TCA Reporting has eight views: view 1 represents the header information and payload information related to the facility sector assets; view 2 and 3 represent the transportation sector assets, view 4 captures the water sector assets, views 5 and 6 show the wastewater sector assets, view 7 represents the solid waste management sector assets, and view 8 (not shown here) represents the summary of the sectorial costs. A variety of the TCA information was represented in the message templates that made it suitable for different types of municipalities (city, town, district, and village municipalities). Different views of the formalized message templates represented in Figure 5-10 and Figure 5-11 were created in MS InfoPath, which were implemented in the AIIS.

5.7 Ontology Evaluation

According to Gomez-Perez (2001), ontology evaluation is carried out from two perspectives: ontology verification and ontology validation. The *ontology verification* focuses on judging the content of an ontology with respect to specified requirements formulated in a set of competency questions. These are the questions that the ontology should be able to answer. The *ontology validation* focuses on judging the content of an ontology from a real-world perspective through industry experts. In other words, the ontology verification means the knowledge model is built correctly, whereas the ontology validation means the correct knowledge model is built.

A criteria-based comprehensive framework was devised to evaluate the TCA_Onto (both verification and validation) as shown in Table 5-1. The framework shows the criteria, measures, and evaluation tools used to evaluate the TCA_Onto. The criteria used to evaluate the TCA_Onto include: consistency, conciseness, completeness (Gomez-Perez, 1996), correctness (Guarino, 1998), and clarity (Gruber, 1995 and Yu *et al.* 2007).

Table 5-1 Tangible capital asset ontology evaluation framework

Ontology Evaluation Framework				
Criteria	Measure	Ontology Evaluation Tools		
		Verification		Validation
		Automated Reasoner	Competency Questions	Expert Review
Consistency-Inconsistency error	i. Cirulatory errors	√		
	ii. Partition errors	√		
	iii. Semantic inconsistency errors		√	
Conciseness-Redundency error	i. Grammatical redundency errors	√		
Completeness-Incompleteness error	i. Incomplete concept classification		√	√
Correctness-Class definition error	i. Identity-identify real world class definition		√	√
Clarity-Communication error	i. Class description communication error			√

Consistency judges the level to which concepts represented in the ontology are consistent, i.e. contradictory conclusions cannot be drawn from the definitions of the concepts. Three measures were used to check the consistency of the TCA_Onto: circulatory error, partition error, and semantic inconsistency error. *Conciseness* judges the level to which the knowledge represented in the ontology is concise, i.e. no redundant concepts are represented in the ontology. The grammatical redundancy error was the measure used to check conciseness of the TCA_Onto. *Completeness* judges the level to which a knowledge representation is complete. Completeness is measured in terms of incompleteness in the knowledge representation because no measures are developed as yet to measure the completeness of an ontology (Yu *et al.* 2007). *Correctness* judges the accuracy of the knowledge representation from a real-world perspective. The identity error was used to measure the correctness of the TCA_Onto. *Clarity* indicates the degree to which the knowledge representation is clear and understandable. The class description communication error was used as the measure to evaluate the clarity of the TCA_Onto.Three tools were used to evaluate the ontology: automated protégé reasoners, competency questions, and expert review. The automated Protégé reasoners (Protégé, 2014) are applications built-in to Protégé that can automatically check the consistency and conciseness of the knowledge representation. Three reasoners—FaCT++, Pallet, and RacerPro 2—were used to verify the class hierarchy represented in the TCA_Onto. The automated reasoners were run to check for inconsistencies in the TCA_Onto. The results of the reasoners based verification of the TCA_Onto is presented in Appendix F, Figure F-1 (a), (b) and (c). The results indicate that the TCA_Onto is consistent and concise.

Competency questions are another tool that was used to verify the TCA_Onto. Based on the requirement analysis, a set of five requirements was identified as described previously in the methodology section. For requirement 1, a set of questions was developed (as follows) that the TCA_Onto should be able to answer. (i) Does the ontology represent assets related to the transportation system? (ii) Does the ontology define different types of bridges? (iii) Does the ontology specify water system assets? (iv) Are wastewater system assets identified and defined in the ontology? (v) Does the ontology reflect TCAs related to solid waste management? (vi) Does the ontology capture different types of facility assets? Moreover, the following four questions represent the requirement 2 to 5 respectively: Does the ontology represent TCA knowledge according to the notion of generalization-specialization of concepts? Is the TCA knowledge organized according to the notion of composition-aggregation of concepts? Does the ontology capture attributes of TCAs? Does the ontology incorporate a variety of relationships between concepts?

The CQ-based verification of the TCA_Onto is presented in Appendix F, Table F-1. Each of these questions was checked manually to measure semantic inconsistency errors, incomplete concept classification errors, and identity errors. Each error was measured in terms of the percentage compliance defined as the sum of the CQs in error divided by the total number of CQs multiplied by 100. The percentage compliance was recorded as full compliance (FC), partial compliance (PC), and non-compliance (NC). A full compliance means a CQ is fully error-free; a partial compliance is in-between two extremes, and a non-compliance means a CQ is fully erroneous for a specific measure. The results of the CQ-based verification analysis indicate that the TCA_Onto was 100% free of semantic inconsistency errors; however, for incomplete concept classification and identity measures, the percentage compliance was 80% and 20% for full and partial compliance respectively. These results indicate a satisfactory performance, which means the knowledge represented in the TCA_Onto was accurately modelled.

The TCA_Onto was validated through three experts in the domain of infrastructure management using three criteria: clarity, completeness, and correctness. Each of the experts had more than 15 years of experience in managing different types of infrastructure systems. They were extremely familiar with different infrastructure systems being owned, operated, or managed by municipalities. They were moderately familiar with data or information modeling and TCA reporting under PSAB-3150 reporting requirements. A structured questionnaire (attached at Appendix H) was used for the TCA_Onto validation. The questionnaire was composed of six sections. The first section captures respondents' profile information, while the second section contained questions related to respondents' familiarity with the domain of infrastructure management, data modeling, and TCA reporting. The third, fourth, and fifth sections contained questions related to clarity, completeness, and correctness of the TCA_Onto. The sixth section represents the overall assessment of the TCA_Onto. To assess clarity, completeness, and correctness of the TCA_Onto, a set of concepts (TCAs) from the four infrastructure sectors (transportation, water, wastewater, and solid waste management) and the facility sector was selected and represented in the questionnaire. The respondents were asked to rate the concepts (TCAs) on a scale of 1 (strongly disagree) to 5 (strongly agree). Each respondent rated each concept represented in the questionnaire and an average score was calculated, which ranged from 4 (agree) to 5 (strongly agree). The detailed results were compiled and represented in Appendix F, Table F-4 for clarity, Appendix F, Table F-6 for completeness, and Appendix F, Table F-8 for correctness. The results indicate that all the respondents were in universal agreement on the clarity, completeness, and correctness of the TCA_Onto.

The results were also tested for statistical significance using the ANOVA two-factor without replication technique. The analysis was conducted at alpha or "p" value of 0.05 and 95% confidence level. The detailed results of the statistical analysis are shown in Appendix F, Table F-5 for clarity, Appendix F, Table F-7 for completeness, and Appendix F, Table F-9 for correctness. The null hypothesis states that there is no significant difference between the responses of the respondents. For all the three criteria, the value of "F" was less than "F_{cri}" and the value of "p" was greater less than 0.05, indicating that the null hypothesis was to be accepted. This means that there was no significant difference between the responses of all the respondents and there is universal agreement on the clarity, completeness, and correctness of the knowledge represented in the TCA_Onto.

5.8 Conclusions

Municipal infrastructure organizations use both computer-based and paper-based information systems to manage their infrastructure systems. These organizations find it difficult to exchange TCA data due to heterogeneity of TCA data formats, lack of formal descriptions of various classes of TCAs, and lack of component-wise aggregation of TCAs.

To address these issues, the TCA_Onto was developed at two levels of abstraction: the TCA_Kernel_Onto and TCA_Extended_Onto. The TCA_Kernel_Onto represents a thin structure of the TCAs at a very abstract level. It has four core modalities of the TCAs: individual, function, composition, and sector asset modality. The TCA_Kernel_Onto was further extended to develop the TCA_Extended_Onto, which represents detailed taxonomies of the TCAs in the facility and four infrastructure sectors: transportation, water, wastewater, and solid waste management.

The TCA_Onto was built using an eleven step hybrid methodology developed from a combination of existing ontology development approaches. The knowledge represented in the TCA_Onto was organized based on the individual modality that was used to define and formalize the MTs for the AI&CAR/TCA Reporting. In the AI&CAR/TCA Reporting, different municipalities send the TCA information to the provincial government for financial planning and budget allocation. A prototype AIIS was developed as part of this research work that collects and analyzes the TCA data received from various city, district, town, and village municipalities. The formalized message templates were implemented in the AIIS, which is discussed in detail in Chapter 9.

The municipalities own, operate, and manage numerous TCAs in various sectors; therefore, multiple view MTs were defined with each view representing the TCA information in a specific sector. The message template defined for the AI&CAR/TCA Reporting was composed of eight views. View 1 represents assets in the facility sector, view 2 and 3 show road and bridge TCAs in the transportation sector, view 4 captures water sector TCAs, view 5 and 6 represent wastewater sector TCAs, view 7 shows solid waste management sector TCAs and view 8 captures the summary of sectoral costs. The TCA_Onto was verified and validated as part of the ontology evaluation using a criteria based approach. The results of the ontology evaluation were found to be satisfactory.

Chapter 6 Transaction Formalism Protocol Specification

6.1 Introduction

In response to the research work "how to formalize transactions?", an ontology-supported Transaction Formalism Protocol (TFP) was developed. The proposed TFP consists of two parts: ontology and protocol. The ontology part of the proposed protocol includes the development of the Transaction Domain Ontology (Trans_Dom_Onto)—Objective 2 (a) and Tangible Capital Asset Ontology (TCA_Onto)—Objective 2 (b), which were discussed in Chapter 4 and 5 respectively. The protocol part includes an eight-step methodology devised to formalize transactions in infrastructure management. The protocol was developed from two different perspectives: TFP Protocol Specification—Objective 3 (a) and TFP Tool—Objective 3 (b).

This chapter[6] consists of eight sections that describe the development and evaluation (verification) of the TFP Specification in the domain of infrastructure management. The TFP Specification is a conceptual model that describes the process of developing the protocol and identifies inputs, controls, mechanisms, tools/techniques, and outputs for each step of the protocol. On the other hand, the TFP Tool defines a set of computer-based forms and guidance that the transaction development personnel can use to define transactions in the domain of infrastructure management. The TFP Tool development and validation is presented in Chapter 7 and a brief introduction of the TFP Tool is presented in this chapter. The TFP Specification was evaluated against a set of ten modeling requirements as described towards the end of this chapter.

6.2 Review of Existing Formalization Techniques

The proposed TFP Specification was developed based on the review of work process and communication formalization standards in the non-AEC/FM and AEC/FM industries. In the non-AEC/FM industry, the primary references underlying the development of the proposed TFP Specification in this chapter include: Open Electronic Data Interchange, Open-EDI (ISO, 1995), United Nation's Center for Trade Facilitation and Electronic Business

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[6] A version of the chapter is published in the Construction Innovation: Information, Process, Management Journal.

Zeb, J. and Froese, T. (2013). "Infrastructure Management Transaction Formalism Protocol Specification: A Process Development Model", Construction Innovation: Information, Process, Management Journal, Volume 14, Issue 1, pp 69-87. The main focus of this paper was on the development and verification of the Transaction Formalism Protocol Specification in the domain of infrastructure management.

(UN/CEFACT) Modeling Methodology, UMM (UN/CEFACT, 2003), the electronic business Extensible Markup Language, ebXML (ISO, 2004-05), RosettaNet, RN (Damodaran, 2004). In the AEC/FM industries, the most important references are: Information Delivery Manual, IDM (IAI-IDM, 2007), Model View Definition, MVD (IAI-MVD, 2005), Voorwaarden Scheppen Voor Invoering Standaardisatie,VISI (VISI, 2007), Construction Objects and Integration of Processes and Systems Engineering Method, COINS-EM/CEM (Schaap *et al.* 2008). A detailed analysis of these references is presented in Chapter 1, Section 1.4.4.

6.3 Development Methodology for the Transaction Formalism Protocol

The goal of this research was to produce a process re-engineering tool or, more specifically, a process modeling technique with a specific focus on formalizing communications for IT communication management in the domain of infrastructure management. Hence, the unit of analysis focuses on the information flows (transactions) that take place within the infrastructure management industry (in particular, the transaction control and meta-data information rather than the data content—payload—of the transaction). Much of the content of this unit of analysis is generic to all formal information exchanges, but some elements are specific to the field of infrastructure management (e.g. the roles that senders and receivers may have with respect to the infrastructure project).

Furthermore, because the overall goal is a systems development objective, the research methodology adopted was a traditional information systems design approach of moving from analysis of existing systems to the design and testing of an improved system. This methodology follows Adesola and Baines (2005), who developed a business process improvement methodology using the two steps of reviewing and analyzing current frameworks/methodologies, and then selecting a few of these based on the key selection criteria. This systems design methodology considers two main layers, a data layer and a process layer. For the data layer, the IAI-IDM (2007) and Schaap *et al.* (2008) emphasize the use of information models to achieve interoperability between information systems of infrastructure organizations. The research reported in this chapter follows this approach, using ontologies as a form of information model because of their semantic richness and unambiguous description of the knowledge representation. The ontology for the design and management of transactions in the domain of infrastructure management was developed using a ten-step approach, which is discussed in detail in Chapter 4. For the process layer, the research follows the process used by Schaap *et al.* (2008), who used IDEF0 models for the design of the COINS-CEM standard in order to create agreements on working methods and the organization of production processes.

The research began with a review of existing literature and systems used in practice, which identified that relevant approaches existed, but that these did not fully address the identified requirements. Therefore, the research methodology adopted a principle of building upon the best practices of the existing approaches, where this was possible. In order to contribute to the body of knowledge in this field, an approach of formally defining the relevant concepts found in the existing approaches using ontologies was also adopted. Consequently, the methodology followed a four-step approach for building upon the existing approaches and extending them as necessary: identify and select existing relevant standards, benchmark existing standards, link and build on existing standards, and develop the TFP.

The *first step* was to identify and select a set of relevant standards, methodologies, and individual efforts in both the AEC/FM and other industries. The criterion used to identify and select these standards (IDM, VISI, UN/CEFACT, ebXML, and RosettaNet) was relevance to the domain of interest (i.e. work process and communication formalization).

In the *second step*, each standard was assessed in terms of general description, objectives, main components and shortcoming.

The *third step* involved adopting and extending components from the selected standards to develop the proposed TFP. Figure 6-1 shows the selected standards (rectangles with rounded corners), selected concepts (rectangles with rounded sides), and their relationships with the concepts used in the proposed TFP (rectangle with gray background).

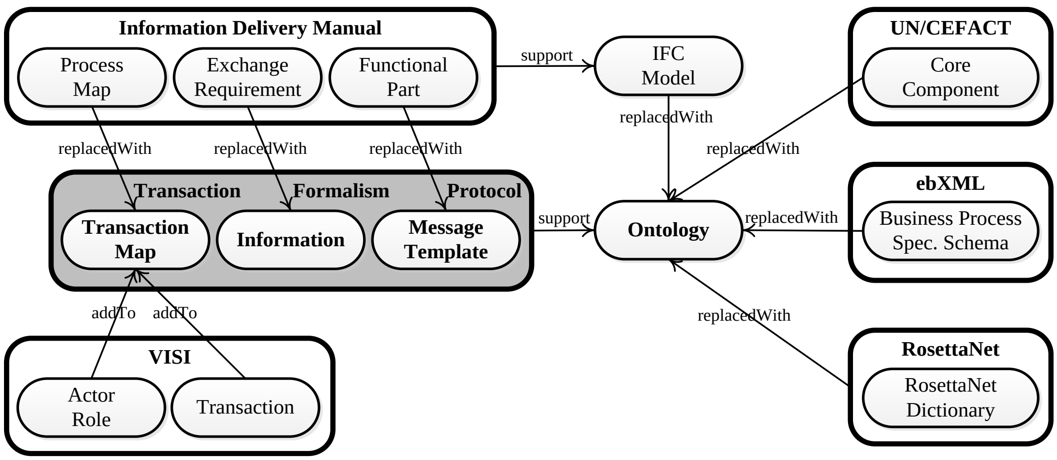

Figure 6-1 The components (rectangles with rounded sides) of relevant process formalization standards (rectangles with rounded corners) that correspond to similar components of the proposed protocol

As shown in Figure 6-1, the proposed TFP is based on previous standards by identifying the components from each of them that the researchers considered to provide best practices, and adopting these ideas by either extending or replacing them with similar components that were tailored to the domain of data transactions within the infrastructure industry. Each idea adopted from existing standards is redefined to support the design, implementation, and management of transactions in the area of infrastructure management. The definitions of these concepts are as follows.

In the IDM (IAI-IDM, 2007), a *process map* is a set of work activities, an *exchange requirement* is the definition of the information that is exchanged between the parties in a given process, a *functional part* is a unit of information that supports implementation of an exchange requirement into software, and the *IFC model* is a data model that represents all important information within the domain of building construction. The IDM supports the implementation of the IFC model by defining a specific sub-set of the IFC model as a functional part within a given exchange requirement. Within UN/CEFACT (2003), a *core component* is a reusable building block that is either a single or collection of pieces of business information (e.g. message date). In ebXML (ISO, 2004-05), a *Business Process Specification Schema (BPSS)*, supports the design of business collaboration, specifically for commercial transactions. According to the Damodaran (2004), the RosettaNet *dictionary* provides the semantics of business and technical objects so that it can be used unambiguously in the design of transactions. “The collection of messages for the finalization of the procedure and the establishment of the order is called a transaction in VISI” (VISI, 2007). Moreover, the VISI standard specifies actor roles, but it is not explicitly defined. As part of this research work, a transaction is defined as "any communication or interaction between the sender and receiver roles that make up the information flow through a single or collection of a sequenced set of messages" (Zeb and Froese, 2012). A *transaction map* specifies the number and sequence of atomic transactions between different roles. *The actor role* defines the behaviors that the transaction actors play is a given business context. *Information* is data (a series of atomic and disconnected facts, statement of event or observation) that is processed, analyzed, and correlated to a context to make it useful for the user, and is required to be exchanged in a given transaction. A *message template* (MT) represents tangible (written) information in a structured way that is instantiated each time some information is exchanged between the parties in a given transaction. Finally, *ontology* refers to the Trans_Dom_Onto that was developed as part of this research to represent knowledge related to transactions in the infrastructure management segment of the AEC/FM industry.

The *fourth step* was to develop a step-by-step procedure that describes how to capture, define, implement and monitor these components to create transaction specifications in the domain of infrastructure management. Moreover, the TFP protocol represents a set of components as defined above; however, this chapter focuses only on the protocol development process, not on the protocol as a whole.

6.4 Transaction Formalism Protocol Architecture

The TFP was developed at two levels of abstraction: TFP Specifications and TFP Tool. The TFP Specification is a conceptual model that describes the process that transaction development personnel can follow to formalize a Transaction in terms of the inputs, controls, mechanism, tools/techniques, and outputs for each step. To implement the specification, the TFP Tool provides a set of computer-based forms that support some of the steps of the TFP Specification so that transaction development personnel can follow the specification in practical scenarios while defining transactions. This chapter discusses the development process of the TFP Specifications, while introducing the TFP Tool briefly. The transaction development personnel use the TFP Tool to formalize transactions to create transaction specifications. These specifications can then be implemented in IT systems, where the end users from industry would input the transaction data as part of the information exchange processes.

6.5 Transaction Formalism Protocol Specification Development

The proposed TFP is an eight-step procedure that users can follow to formalize data transactions. The TFP takes two different forms: TFP Specification and TFP Tool. The TFP Specification is a detailed step-by-step description of the tasks that users should carry out: it serves as the guidebook to lead users through the process of creating transaction specifications. The TFP Tool is a form-based application; users enter the appropriate information to describe the data transaction and the tool produces the corresponding formal transaction specification document. This chapter describes the development of the TFP Specification in detail in the following sections; followed by a brief introduction of the TFP Tool in Section 6.6.

6.5.1 Transaction Formalism Protocol—Process Model

The Figure 6-2 shows an overall process model of the eight steps that comprise the TFP. The model is presented using IDEF0 function modeling notion (NIST, 1993), which shows each step as a process or function depicted as a rectangle, with arrows flowing in or out representing inputs (left), controls (top), mechanisms (bottom), and outputs (right).

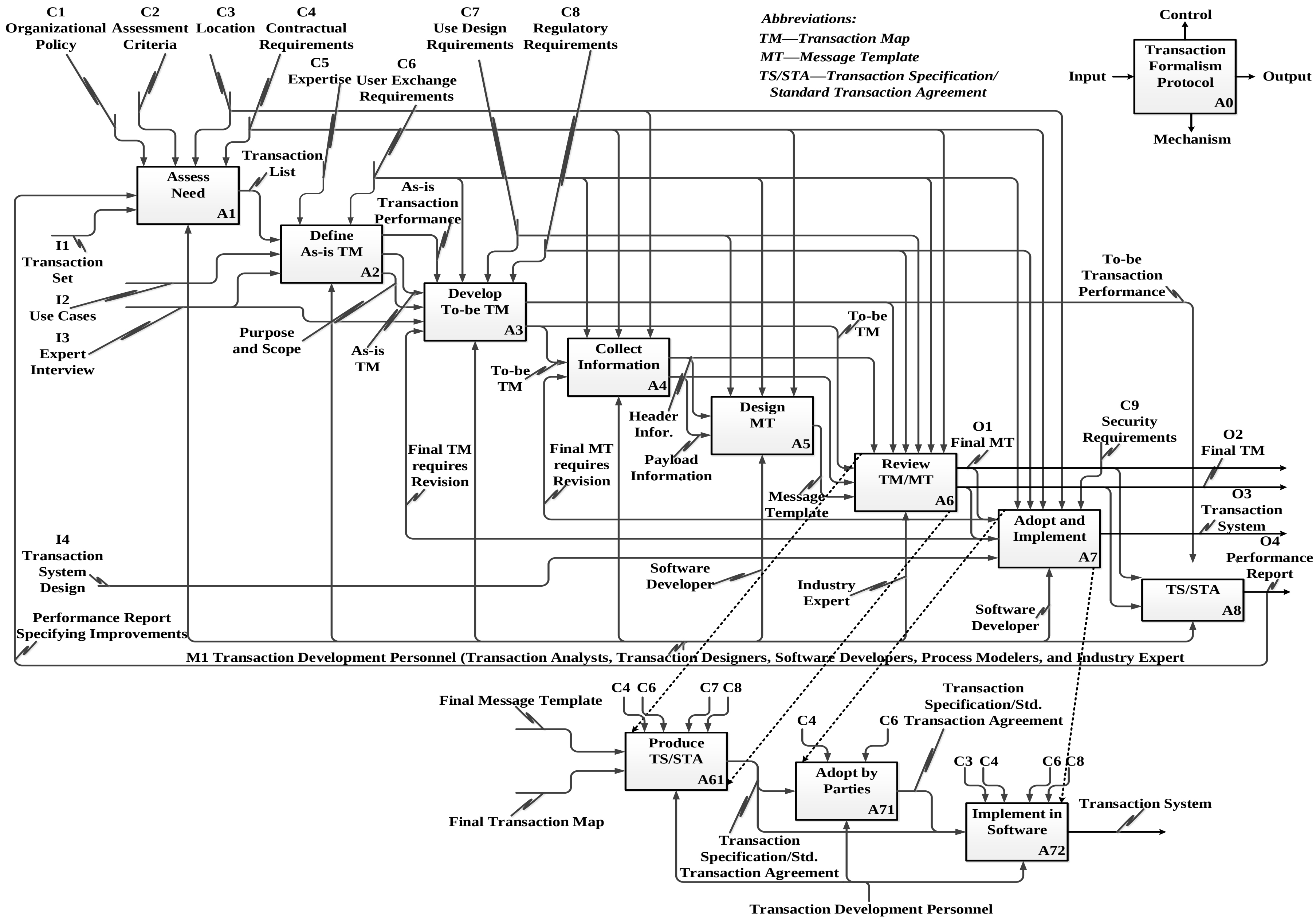

Figure 6-2 A process model of the overall transaction formalism protocol

The IDEF0 technique was selected for the following reasons: *Comprehensiveness*—the technique has the capability to represent system functions (i.e. actions, activities, processes, operations) graphically at any level of granularity. *Ease of use*—the technique is simple to use and easy to learn. *Consistency*—as a modeling standard, the IDEF0 technique promotes consistent development of the functional models. *Time tested*—the IDEF0 is a time-tested and well-proven technique used by a variety of government and private agencies to create various function models. *Software support*—a variety of commercially available graphical software supports the development and analysis of IDEF0 diagrams.

6.5.1.1 Inputs

Inputs are data or objects (abstract and physical) that are required by a function and transformed into useful output. Inputs are either resulting inputs (which are the outputs of a preceding step), or else they are applied inputs. The TFP identifies four key applied inputs: I1-transaction (set), I2-use cases: I3-expert interviews: I4-transaction system design.

6.5.1.2 Controls

Controls are the conditions, circumstances, laws, regulations, requirements, and objects (abstract or physical) that govern the transformation of inputs into useful outputs. Many of the requirements imposed on the data transactions are represented as controls. As with inputs, resulting controls are outputs of the preceding steps while applied controls are introduced from sources external to the process model. Nine applied controls are defined in the TFP model: C1-organizational policy, C2-assessment criteria, C3-location, C4-contractual requirements, C5-expertise, C6-user exchange requirements, C7-user design requirements, C8-regulatory requirements, and C-9 security requirements.

6.5.1.3 Mechanisms

Mechanisms are the means used to perform a function of transforming inputs into useful outputs. In the TFP, mechanisms refer to the human resources required, specifically, M1-the transaction development personnel refer to transaction analysts, transaction designers, software developers, process modelers, and industry experts. Depending upon the knowledge, experience, and training of individuals, a single individual could perform all of the proposed steps, or different individuals could be involved in each step. Therefore, these human resources are not modeled separately for each of the steps in the overall process model, except to note that those involved in developing and implementing message templates typically have software development expertise while those carrying out the review step should be industry experts.

6.5.1.4 Tools/Techniques

The TFP describes a number of tools and techniques that can be used to support the process formalization work. Examples include process flow charting, unified modeling language (UML) sequence diagrams, and ontology web language (OWL). These are not included in the overall process model shown in Figure 6-2, but they are listed in the detailed step-by-step descriptions. The definitions of the complete set of tools/techniques are given in Appendix I.

6.5.1.5 Outputs

Outputs are abstract or physical outcomes produced by a function and used as inputs to subsequent functions (applied outputs), or defined as a deliverable of the overall TFP process (resulting outputs). The TFP resulting outputs are: O1-final message template, O2-final transaction map, O3-transaction system, and O-4-performance report.

6.5.2 Transaction Formalism Protocol Steps

Each of the eight steps defined in the TFP process model has been fully developed. A brief description of each step is summarized in the following sections and depicted in Figure 6-3 and Figure 6-4.

6.5.2.1 Step 1—Assess Needs

The first step is to assess organizational needs to identify transactions that have the greatest potential for improvement. As shown Figure 6-3 (a), a number of techniques can be used to identify, assess, and prioritize possible transactions. In this research work, criteria-based evaluation was used, where the criteria for selecting candidate transactions include: criticality, cost, frequency, complexity, contractual requirements, regulatory requirements, and likelihood of receiving management attention. The output of step 1 is one or a set of transaction(s) selected for formalization.

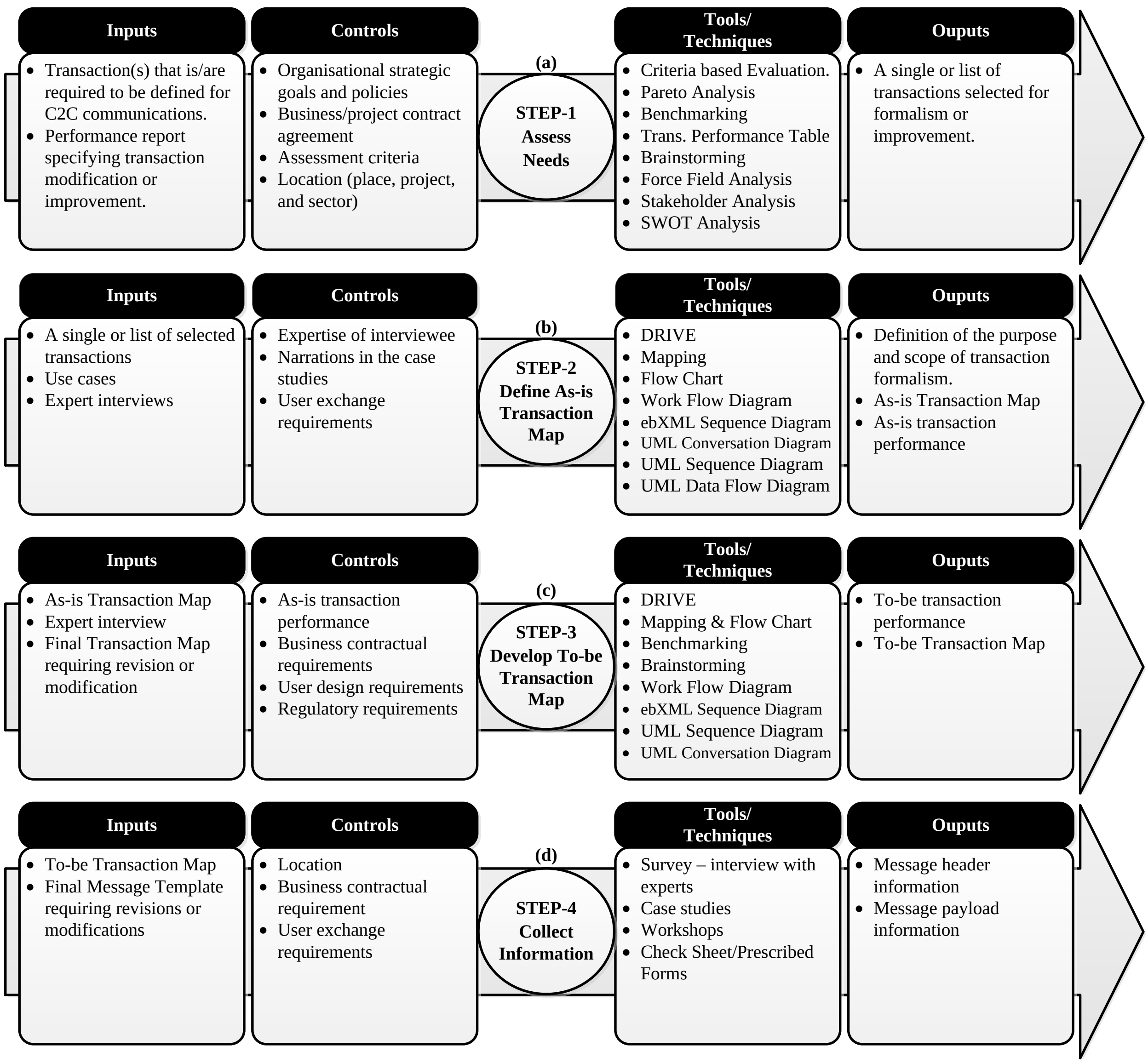

Figure 6-3 Inputs, controls, tools/techniques, and outputs of step 1 through 4: (a) Assess needs; (b) Define as-is transaction map; (c) Develop to-be transaction map; and (d) Collect information

6.5.2.2 Step 2—Define As-is Transaction Map

As-is transaction maps of the selected transactions are developed to represent the existing information flow between the involved parties (Figure 6-3 (b)). As-is transaction maps are created in graphical form to show the number of atomic transactions (individual interactions between sender and receiver roles that results in the exchange of information) and their sequence. These transaction maps can be captured from use cases describing the existing communications or from interviews with the industry experts. A number of tools are available to capture As-is transaction maps; in this research work, flow charts and sequence diagrams were used.

6.5.2.3 Step 3—Develop To-be Transaction Map

The next step is to identify improvements to the As-is transaction and produce a To-be transaction map (Figure 6-3 (c)). Transactions can be improved using one or a combination of the three forms: *First,* process improvement transforms the communication process, adding or deleting activities from the As-is transaction map to satisfy new requirements, (e.g. adding or deleting an acknowledgement atomic transaction to the As-is transaction map). *Second*, information improvement changes the way information is exchanged between the parties, e.g. making the information more structured and computer-interpretable. *Third*, mode improvement alters the mode or channel through which the transaction is accomplished in order to enhance the efficiency and effectiveness of the communication, e.g. changing from a fax transmission to a web-based file exchange.

6.5.2.4 Step 4—Collect Information

This step captures the detailed information required in the transactions (Figure 6-3 (d)). In each atomic transaction, information is exchanged between the parties through a message template that represents two types of information: header and payload information. The *header information* is the meta-information about a transaction, e.g. the name, purpose, and definition of the communication; name, role, and address of the sender and receiver roles; and temporal information. The *payload information* is the core information content that parties must exchange to accomplish a transaction successfully, e.g. length, diameter, quantity, and cost of a pipe. In this research work, use cases and expert interview techniques were used to collect the detailed transaction information. Experts were typically managers in the domain of municipal infrastructure management.

Depending upon the domain of interest (sector), complexity of transaction, type of transaction, and number of diversified stakeholders requiring information, one or more experts are needed to assess or collect the payload information for the design of structured message templates. Information collection is done in three steps: understand the purpose of the transaction, understand and capture stakeholder requirements, and document the information.

6.5.2.5 Step 5—Design Message Template

Message templates are defined (Figure 6-4 (a)) based on the header and payload information collected in step 4. A message template represents the required header and payload information in a well-structured and computer interpretable format. A single message template flows between the parties in each atomic transaction. To achieve message-based interoperability between information systems of infrastructure organization, the design of the message templates should be based on an information/knowledge model—the ontology. A set of tools can be used to define a message template. Microsoft Infopath Designer was used in this research for the design of message templates.

Upon completion of the message template, all of the key deliverables that describe the proposed transaction are assembled into a transaction specification. This is the formal transaction specification that includes the To-be transaction map between specific actor roles, the content and format of the message templates, and the complete set of form-based documentation of the process of transaction formalization.

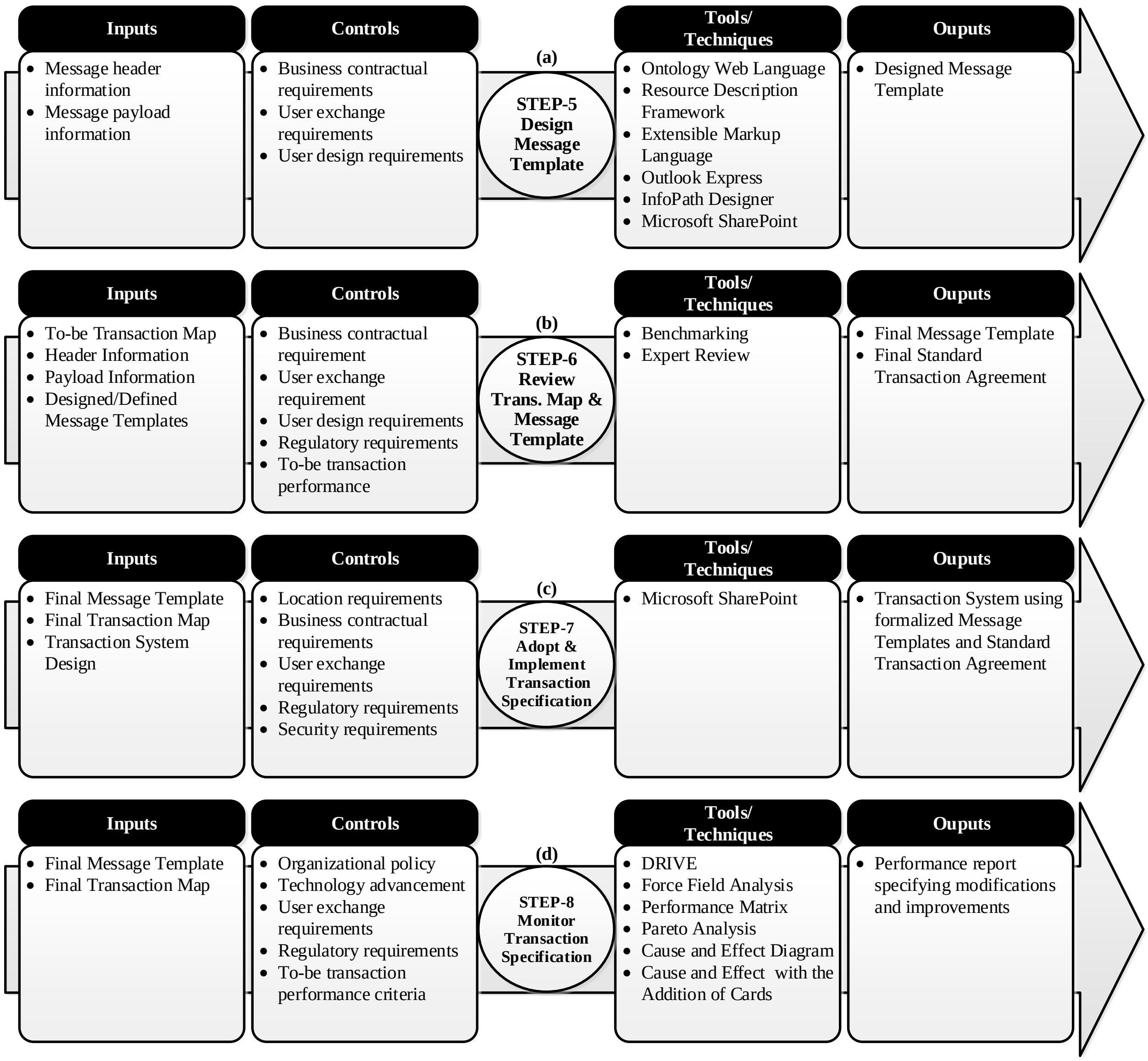

Figure 6-4 inputs, controls, tools/techniques, and outputs of step 5 through 8; (a) Design message template; (b) Review transaction map and message template; (c) Adopt and implement the transaction specification; and (d) monitor transaction specification

6.5.2.6 Step 6—Review Transaction Map and Message Template

In this step, industry experts review the contents of the transaction specification (Figure 6-4 (b)) to provide quality assurance in the design of the communication process (To-be transaction map), the exchange information (header and payload), and the format and structure of information representation (message template). This review is particularly important in cases where the message designer is an IT specialist but not a domain expert. The review should consider the business contractual requirements, user information exchange requirements, user design requirements, regulatory requirements, and To-be transaction performance. It may identify shortcomings and propose changes and modifications to the transaction specification. It then remains for the transaction specification to be implemented (Figure 6-4 (c)). This could range from trivial cases—e.g. a data set exchanged in the form of a spreadsheet file of a specified structure, transmitted as an email attachment—to complex cases—e.g. where custom software applications are created around the transaction specification. In this research, a pilot solution was developed that lies somewhere between these two extremes, implementing transaction specifications as workflow processes in Microsoft SharePoint, a collaboration platform that includes workflow management capabilities.

6.5.2.7 Step 7—Adopt and Implement Transaction Specification or Standard Transaction Agreement

With the transaction specification finalized, it remains for the parties involved in the transaction to formally adopt the specification as their plan and commitment for how the communications will take place. In some cases, the communicating parties developed the transaction specification themselves to address a specific need and their adoption of the specification is implicit. In other cases, the transaction specifications may have been developed unilaterally by one of the parties, or may have been developed independently by third parties (e.g. standards bodies or software vendors), and the adoption of the agreement by all parties is a distinct and explicit requirement.

6.5.2.8 Step 8—Monitor Transaction Specification or Standard Transaction Agreement

After the transaction specification has been implemented and deployed, it is advisable to monitor its performance over time to find opportunities for improvement (Figure 6-4 (d)). The monitoring should assess the performance of the communication process relative to expectations, seek feedback from end users, and look for changes to the communication requirements arising from the dynamic AEC/FM environment.

6.6 Transaction Formalism Protocol Tool and its Application

The TFP Tool is a form-based software application developed to assist transaction development personnel to formalize transactions efficiently and effectively. For several of the steps of the proposed protocol, a form was created representing information that is required for the design, implementation, and monitoring of the transaction map and message templates. Form-1 relates to the needs Assessment, Form-2 defines the As-is transaction map, Form-3 develops the To-be transaction map, Form-4 collects the header and payload information, Form-5 represent the message template design, Form-6 reviews the transaction map and message template, Form-7 guides implementation, and Form-8 monitors the transaction performance for further changes or improvements. The TFP Tool was implemented in Microsoft Excel to allow users to easily enter information for each step of the protocol in a structured and consistent way, explicitly defining the data elements to provide a common understanding of the terms used. The protocol tool is kept simple so that transaction development personnel could easily use and understand the forms. An example of one of the forms from the TFP Tool (step 1—assess needs) is shown in Figure 6-5. The example implementation is kept simple so that data elements for each form can be easily defined and understood. Currently, the Excel-based forms are used manually, with the intention that the TFP Tool forms could be incorporated into a more complete system information and workflow management system in the future.

Assess Needs - Step 1	
General Administrative Information	
Name	XYZ
E-mail Address	
Date Conducted	30/05/12 (dd/mm/yy)
Technical Information	
Description of Transaction Selection	
Experts in the domain of infrastructure management identified a list of transactions that have the greatest potential for IT improvement. All the identified transactions obtained same scores; however, it is decided to formalize tangible capital asset reporting transaction first, due to urgent compliance with the Public Sector Accounting Board reporting requirement. Moreover, other transactions on the list will be formalized later.	
Assessment Criteria - (tick all that applies)	

Single or List of Transaction	Manual/ Paper-based	Critical	Costly	Frequent	Liklihood of Mgt.	Complex	Contractual Req.	Regulatory Req.	Total Score
i. Tangible capital asset reporting (PSAB-3150)	√		√			√		√	4
ii. Asset inventory & condition assesssment reporting	√		√			√		√	4
iii. Pavement condition assessment reporting	√		√			√		√	4
iv. Request for proposal	√	√			√		√		4
v. Submission of project as-built information				√	√		√	√	4
vi. Request for services		√		√	√		√		4

Figure 6-5 A form for the transaction formalism tool for supporting the needs assessment step in the domain of infrastructure management

The assess needs form is used to support the process of listing different transactions that may be found within a given context and selecting those that are to be the subject of the formalization effort. The form is divided into two sections. The *general administrative information* section captures information about the individual conducting the needs assessment. The *technical information section* captures a brief description of the selected transaction, the rationale for selection, and the assessment criteria.

The assessment criteria section supports the ranking of the potential transactions. The user lists one or more transactions that are of potential interest in the domain. A rigorous objective assessment is not required here, but a simple criteria-based assessment of the potential transactions can assist the user to organize their ideas about the relative importance of different facets of the potential transactions. Each criterion is kept subjective, so that the user has the flexibility to identify transactions for IT improvement in accordance with their specific environment and context. Use of the criteria is kept simple through clicking the criterion that applies during the transaction identification and selection. A total score is calculated by simply adding the number of criteria that apply to each transaction, with higher scores indicating that the transaction more fully meets the defined criteria. This is intended only to provide some guidance to the user, who can take broader issues into consideration to choose the highest priority transaction.

In Figure 6-5, the form was completed to carry out a needs assessment in the domain of infrastructure management based on a survey conducted as part of this research. Industry experts from different municipalities were interviewed to identify transactions that have the greatest potential for IT improvement.

A list of transactions identified during the survey were entered into the form and assessed against the criteria. In this case, all transactions yield the same assessment score, and other considerations were taken into account to select the tangible capital asset reporting as the highest priority transaction. In the Tangible Capital Asset Reporting process, Asset Inventory and Condition Assessment data are exchanged between different departments of a municipality and between municipalities and the provincial government for financial planning in order to allocate funds to various municipalities based on their requirements. Some of the survey respondents commented on the high priority of this transaction because of new regulations requiring this type of reporting.

An important issue is the identification and selection of the individuals to carrying out the needs assessment, since there are a variety of sections or departments in an organization and each individual within these different departments has different priorities, requirements; technical expertise, and professional experience. A good practice could be to carry out the needs assessment at the department level, and then synthesize the results by the management to align with the organizational goals. Another issue is around the use of the form(s) in terms of its human nature. All the forms of the TFP Tool, including the one shown in Figure 6-5, are to be filled manually; therefore, explicit descriptions of the terms used in the forms are required so that trans-industry consistency is maintained while developing specifications. To address the issue, each term represented in the form was explicitly defined in the Transaction Domain Ontology so that everybody should have a common understanding of these terms. Also, detailed instructions on how to fill the form(s) were developed to ease understanding.

6.7 Transaction Formalism Protocol Evaluation

A verification process was applied to the TFP Specification by assessing it against a set of requirements, along with comparative assessments of a number of other techniques as shown in Table 6-1.

Folmer and Bastiaans (2008), identify the following set of nine quality criterion to evaluate process design methodologies: top-down approach, model-driven approach, iterative, platform non-restrictive, domain modeling, choreography modeling, information modeling, formal verification method, and tool/techniques support. A design methodology or protocol is said to be adequate if it fulfills all of these subjective criteria. In this analysis, a set of previously developed process design methodologies, standards, and protocols in the AEC/FM and other industries were compared with the proposed TFP Specification against the above-mentioned criteria. Each criterion was assessed subjectively as follows: *Fully satisfied* (+) means the protocol or methodology incorporates all aspects of a quality criterion. *Partially satisfied* (-) means the protocol or methodology incorporates some aspects of a quality criterion. *Non-satisfied* (x) means the protocol or methodology doesn't incorporate any aspects of a quality criterion. Table 6-1 shows that the proposed TFP Specification fulfills all of the required quality criteria.

Table 6-1 Transaction formalism protocol specification evaluation

		Transaction Formalism Protocol Specification Evaluation									
		Verification Criteria									
S. #	Methodologies/ Standards	Top - Down	Model/ Driven	Iterative	Plateform Independent	Domain Modelling	Choerography Modelling	Information Modelling	Verification Method	Tool Support	Systematic Approach
A.	**AEC/FM**										
1	Information Delivery Manual	-	+	-	x	+	+	+	-	+	-
2	Model View Definition	-	-	-	x	+	x	+	-	x	-
3	VISI	+	+	x	x	-	+	+	-	+	-
4	COIN	+	x	+	x	-	x	+	-	x	-
5	***Proposed TFP Specification***	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**
B.	**Non-AEC/FM**										
1	UMM	+	-	+	+	+	+	+	-	+	-
2	ebXML	+	+	x	+	-	+	+	x	+	-
3	RossettaNet	+	+	x	+	-	+	+	x	-	-
4	Villarreal	+	+	+	+	-	-	-	+	x	x
5	Kim	x	x	x	x	-	-	x	x	+	x
6	Kramler	+	-	x	+	-	-	+	x	x	x
7	Bauer	+	+	x	+	-	+	x	x	x	x
8	Koehler	+	-	x	x	-	+	x	x	x	x
Legends:	Fully Satisfied	+		Partially Satisfied/Not Entirely Clear		-			Not Satisfied	**x**	

The results were analyzed for statistical significance using an ANOVA single-factor technique. The test was set to compare the total score obtained by each methodology or standard against the maximum average score for a fully satisfied criterion. The analysis results (Appendix L, Section L.1, Table L-1 and Table L-2) show a significant difference because the value of "F" was greater than "F_{crit}" (59.70>4.30) with p-value 1.05 x e^{-07} less than the alpha factor 0.050 (95% confidence level), indicating that the null hypothesis was to be rejected. The null hypothesis states that there is no significant difference between the score obtained by different methodologies against the maximum average score for a fully satisfied criterion. Moreover, the proposed TFP Specification methodology obtained the maximum score for the fully satisfied criteria, indicating a satisfactory performance.

In addition to the verification of the TFP Specification, a validation process was applied to the TFP Tool by enlisting domain experts to assess the tool against a set of criteria. A comprehensive validation framework was developed representing the criteria and measures to gauge criteria compliance. According to Adesola and Baines (2005), a set of criteria used to validate the TFP Tool is as follows: *Feasibility* refers to whether the protocol can be applied and followed while defining communications. *Usability* describes that the protocol is easy to apply and use. *Usefulness* captures that the protocol produces useful results. In addition, generalizeability was another criterion that was used. The TFP Tool development and validation is presented in Chapter 7.

The TFP Tool testing and validation are two distinct phases of this research work. The TFP Tool testing in the domain of infrastructure management relates to the tool application, as discussed in the previous section, that was done to refine and fine-tune the protocol to incorporate and represent all requirements of the transaction development personnel. On the other hand, the TFP Tool validation focused on feasibility, usability, usefulness, and generalizability, of the protocol in the domain of infrastructure management.

6.8 Conclusions

Currently, some process and communication formalization methodologies or standards exist in the AEC/FM and non-AEC industries, but it was found that these methodologies do not fully support the design of transactions in the domain of infrastructure. These methodologies lack the step-be-step procedure that transaction development personnel require to define transactions and messages efficiently and accurately for IT improvement. Most of them are process-centric rather than transaction-centric, and most do not address the information modeling component required to describe transactions in the infrastructure management sector. To overcome the gap, a TFP was developed in the domain of infrastructure management. The TFP takes two forms: TFP Specification and TFP Tool.

The TFP Specification is an eight-step procedure developed to aid transaction development personnel to define transactions for IT improvements. The protocol was developed using a four-step methodology; (i) identify and select a set of relevant existing standards; (ii) benchmark existing standards; (iii) link and build on existing standards; and (iv) develop the proposed TFP using the IDEF0 function modeling technique.

The core focus of this chapter was to present the development of the TFP Specification, which is a conceptual model of the proposed protocol. The eight-steps of the TFP Specification include: assess needs, define the As-is transaction map, develop the To-be transaction map, collect information, design the message template, review the transaction map and message template, implement the transaction map and message template, and monitor the transaction specification or agreements. Each step of the proposed TFP was modeled as a distinct function for which inputs, controls, mechanisms, tools/techniques, and outputs were defined. The TFP Tool consists of a set of forms developed for some steps of the protocol. The purpose of the forms is to capture accurate information efficiently and effectively.

The proposed TFP was applied in the domain of infrastructure management to identify and define transactions that have the greatest potential for IT improvement. An Asset Inventory and Condition Assessment Reporting/Tangible Capital Asset Reporting process was identified and selected for improvement using the TFP Tool. The TFP comprised of a set of forms developed for some steps of the protocol. Forms testing and validation is presented in Chapter 7.

As part of the evaluation, a verification process was conducted for the TFP Specification against a set of quality criteria to verify that the model incorporates all the necessary components that are required in a process or communication design methodology. The result of this assessment shows that the TFP Specification fully satisfies the defined requirements. The TFP Tool was validated as part of the evaluation process against a set of criteria including; feasibility, usability, usefulness, and generalizability, and the validation results are presented in Chapter 7.

Chapter 7 Transaction Formalism Protocol Tool

7.1 Introduction

An ontology-supported Transaction Formalism Protocol (TFP) was developed in response to the research work "how to fomalize transactions?". The proposed TFP was developed at two levels of abstraction: TFP Specification—Objective 3 (a), as discussed in Chapter 6 and TFP Tool—Objective 3 (b), as described in Chapter 7.

This chapter[7] consists of nine sections that describe the development, application, and evaluation of the TFP Tool. The TFP Tool is an eight-step procedure developed to: assist transaction development personnel to identify and formalize transactions; provide an easy to use step-by-step procedure; ease software implementation; and assist the monitoring of transaction performance over the life cycle of transactions towards continuous improvement. The proposed TFP Tool includes a set of Excel-based forms and some guidance that the transaction development personnel can use to define transaction specifications. These steps are: assess needs, define As-is transaction map (TM), develop To-be TM, collect information, design message template (MT), review TM and MT, adopt and implement TM and MT, and monitor transaction specification (also referred to as standard transaction agreement). The TFP Tool was successfully applied in the domain of infrastructure management for formalizing Asset Inventory and Condition Assessment Reporting/Tangible Capital Asset (AI&CAR/TCA) Reporting between the municipal and provincial governments. The TFP Tool was validated through industry professionals using an expert interview survey-based approach.

7.2 Related Work Process and Communication Formalization Standards

The TFP Tool was developed based on the review of the state-of-the-art work process and communication formalization standards, methodologies, and techniques in the non-AEC/FM and AEC/FM industries. The most

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[7] Some material from this chapter has been published in the proceedings of the 7th International Structural Engineering and Construction Conference. Additional material has been added to the chapter presented here and is submitted as a journal manuscript for publication.

Zeb, J. and Froese, T. (2013). "Transaction Formalism Protocol in the Domain of Infrastructure Management", Siamak Yazdani and Amarjit Singh (Eds.), New Developments in Structural Engineering and Construction, Research Publishing Services, C-34-271, Seventh International Structural Engineering and Construction Conference (ISEC-7), June 18-23, 2013, Honolulu, Hawaii, USA. The focus of this paper is to provide an abstract overview of the Transaction Formalism Protocol specification and tool.

Zeb, J. and Froese, T. (2014). "Transaction Formalism Protocol Tool in Infrastructure Management", Journal Paper Submitted for Publication. The focus of this paper is on the development, application, and evaluation of the TFP tool developed as part of this research work in the domain of infrastructure management.

important references in non-AEC/FM industry that led to the development of the TFP Tool include: United Nation's Center for Trade Facilitation and Electronic Business Modeling Methodology, UMM (UN/CEFACT, 2003), electronic business Extensible Markup Language, ebXML (ISO, 2004-05), and RosettaNet (Damodaran, 2004). A number of researchers have developed methodologies for business process modeling, which include: model-based development process methodology (Villarreal *et al.* 2006), standardized schema for the business processes formalization (Kim, 2002), and model-driven approach (Bauer *et al.* 2004).

In the AEC/FM industry, the primary references underlying the development of the proposed TFP Tool include: Information Delivey Manual, IDM (IAI-IDM, 2007 and IAI-IDM, 2012), Model View Definition, MVD (IAI-MVD, 2005), VISI standard (VISI, 2007 and VISI, 2011), and Construction Objects and Integration of Processes and Systems Engineering Method, COINS-EM/CEM (Schaap *et al.* 2008). Detailed analysis of these references is given in Chapter 1, Section 1.4.4.

7.3 Methodology to Develop the Proposed Transaction Formalism Protocol

A four-step approach was used to develop the proposed protocol, as shown in Figure 7-1.

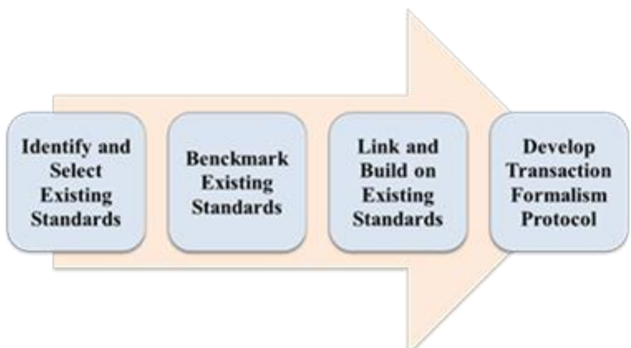

Figure 7-1 Approach to developing the transaction formalism protocol

Step 1: identify and select candidate standards—the first step was to identify a set of the most relevant work process and communication formalism methodologies. In the non-AEC/FM industry, initiatives like UN/CEFACT, ebXML, and RosettaNet were of particular importance. In the AEC/FM industry, IDM and VISI were the most relevant standards. These standards were selected based on a sole criteria—relevance to the domain of interest (i.e. work process and communication formalism).

Step 2: benchmark existing standards—the selected standards were benchmarked in terms of general description, objectives, and core components of each standard. In a subsequent gap analysis, shortcomings of each standard were identified in relation to the non-availability of the support for the design and management of transactions in the domain of infrastructure management.

Step 3: link and build on existing standards—the proposed TFP was constructed by building upon the existing benchmarked standards. Some relevant concepts (components) were chosen from the selected standards, which were then modified and used to develop the TFP. A link was established between different components of the selected standards and the proposed TFP to show how various components were interrelated and how the TFP was built.

Step 4: develop transaction formalism protocol—the proposed protocol was developed using the modified version of the most relevant and important concepts (components) identified in the previous step. In this step, a step-by-step procedure was developed to describe how to capture, define, and implement these components and integrate them in the proposed protocol. The protocol was developed using the Integration Definition Function Modeling (IDEF0) Technique as a Federal Information Processing Standard, FIPS (NIST, 1993). The IDEF0 technique was selected due to comprehensiveness, ease of use, consistency, long-standing use, and availability of software support. According to this standard, each step of the protocol was modeled as a distinct function for which inputs, controls, mechanisms, tools/techniques, and outputs were defined. A *function* represents an action, activity, process, or operation at a finer level of granularity in a given business process model. These five parameters were defined for each function or step of the proposed TFP Specification as discussed in Chapter 6.

7.4 Transaction Formalism Protocol Architecture

The TFP protocol is an eight-step procedure developed to define transactions in the domain of infrastructure management effectively and efficiently. The proposed protocol was developed from two different perspectives; the TFP Specification and TFP Tool as shown in Figure 7-2.

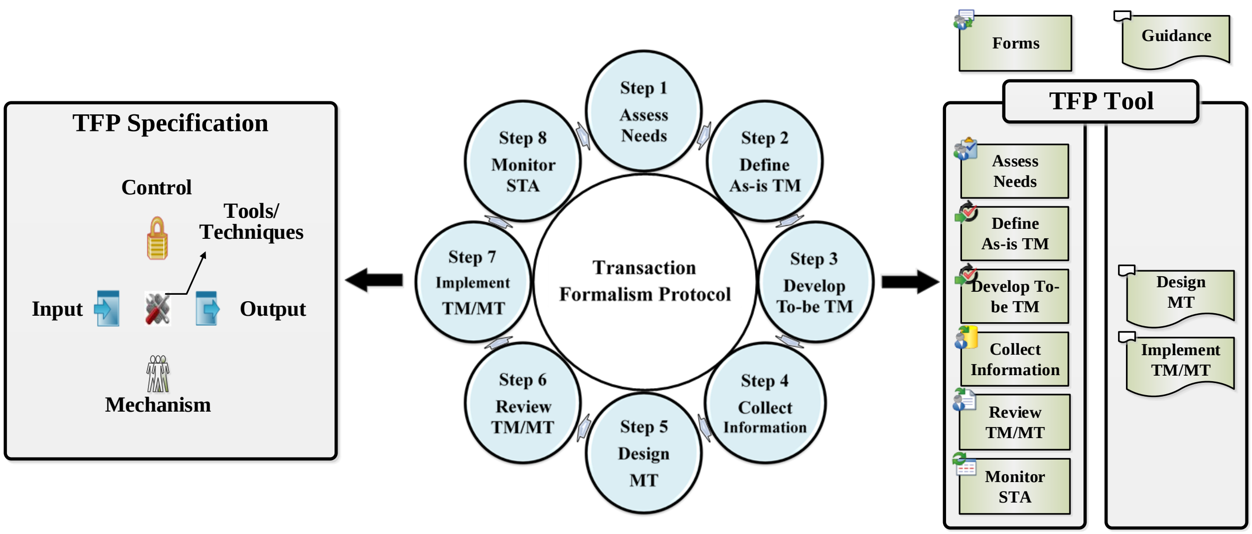

Figure 7-2 Transaction formalism protocol architecture

The *TFP Specification* was developed from a conceptual perspective where each step of the protocol was modeled as a distinct function for which inputs, controls, mechanisms, tools/techniques, and outputs were defined. The TFP Specification was developed using the IDEF0 modeling technique. The TFP Specification provides the formal "instruction set" for creating transaction specifications.

On the other hand, the *TFP Tool* implements the TFP Specification in the form of a software application that the transaction development personnel can use to formalize transactions in practical situations. The TFP Tool is comprised of a set of Excel-based forms and guidance developed for specific steps of the protocol (i.e. forms were developed for some steps of the protocol, whereas for others, only guidance was provided on how to accomplish a specific step). The forms for the TFP Tool were developed in step 1, 2, 3, 4, 6, and 8. The forms were developed to capture information easily, accurately, and consistently while defining transactions. For step 5 and 7, only guidance was provided on how to perform these steps because no data is required to be captured in these steps. The main focus of this chapter is on the development, applications, and validation of the TFP Tool. A brief introduction of the TFP Specification and a detailed description of the TFP Tool follows.

7.5 Introduction to Transaction Formalism Protocol Specification

The TFP Specification defines five parameters for each step of the protocol: inputs, controls, mechanisms, tools/techniques, and outputs. The inputs are the data or objects that are required by a function to transform into useful outputs. The controls are the conditions required to transform inputs into correct and useful outputs. The mechanisms are the means used to perform a function through transforming inputs into useful outputs. The tools/techniques include the necessary support or aid in terms of the procedures and software available to the transaction development personnel to perform a step successfully. The outputs are the data or objects produced as a result of accomplishing a function. The definition of each step of the protocol and the way it can be applied in practical scenarios while defining transactions is elaborated in the subsequent sections. As an example, inputs, controls, tool/techniques, and outputs for step 3 (develop the To-be transaction map) of the protocol are presented in Figure 7-3. A detailed description of the TFP Specification was provided in Chapter 6.

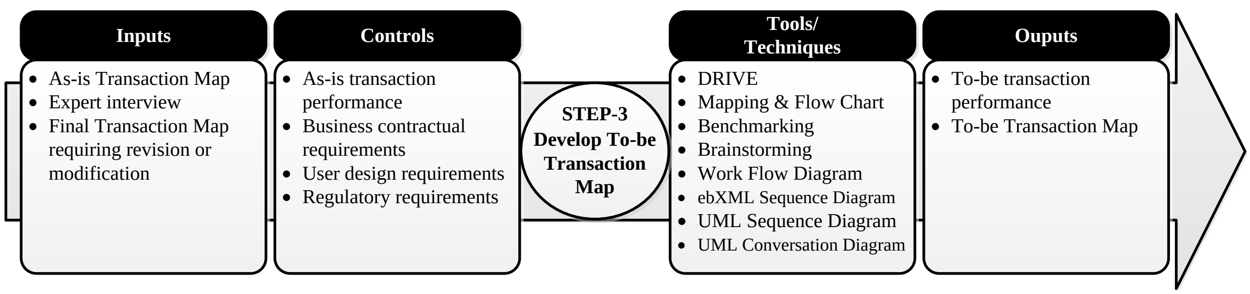

Figure 7-3 Inputs, controls, tools/techniques, and outputs for step-3, (develop the to-be transaction map)

7.6 Transaction Formalism Protocol Tool Development

The TFP Tool comprises a set of Excel-based forms that the transaction development personnel can use to formalize transactions as a prelude to IT improvement. Each form is explained in the following sections.

7.6.1 Step 1—Assess Needs

The assess needs form, shown in Figure 7-4, is used to support the process of listing different transactions that may be found within a given context and selecting those that are to be the subject of the formalization effort. The form is divided into two sections.

General administrative information—captures information about the individual conducting the needs assessment.

Technical information—captures two types of information: a description of the transaction selection and the assessment selection criteria.

Description of transaction selection—briefly describes the process of transaction identification and selection, explaining the rationale for the selection and the assessment criteria used to assess transactions for IT improvements.

Assessment criteria section—supports the ranking of the potential transactions. The user lists one or more transactions that are of potential interest in the domain. A rigorous objective assessment is not required here, but a simple criteria-based assessment of the potential transactions can assist the user to organize their ideas about the relative importance of different facets of the potential transactions. The set of criteria that can be used to carry out needs assessment is defined as follows. *Manual transaction*—in which every aspect (sending, receiving, and interpreting) of a transaction is conducted manually, e.g. paper-based transactions. *Critical transaction*—are context specific and depends on the type of organization, type of information being exchanged, the parties involved, and the time required to exchange accurate information, e.g. PSAB-3150 reporting. *Costly transaction*—are the ones that the management believes to be costly in the current state. *Frequent transaction*—relate to a high number of transactions per unit of time. Frequent and repeated transactions are more likely to justify IT based solutions. *Likelihood of management*—refers to the sole discretion of the management to adopt IT-based solutions for the exchange of information. *Complex transaction*—represents multi-lateral transactions where more than two parties are involved. *Contractual requirement*—contract stipulations sometime require the transaction to be executed using the latest IT. *Regulatory requirement*—certain laws, acts, and regulations govern data exchange between the parties, e.g. PSAB-3150 reporting. Each criterion is kept subjective, so that users have the flexibility to identify transactions for IT improvement in accordance with their specific environment and context. Use of criteria is kept simple through clicking the criterion that applies during the transaction identification and selection. A total score is calculated by simply adding the number of criteria that apply to each transaction, with higher scores indicating that the transaction more fully meets the defined criteria. This is intended only to provide some guidance to the user, who can take broader issues into consideration to choose the highest priority transaction.

<table>
<tr><th colspan="11">Step - 1 Assess Needs</th></tr>
<tr><th colspan="11">General Administrative Information</th></tr>
<tr><td>Name</td><td colspan="10"></td></tr>
<tr><td>E-mail Address</td><td colspan="10"></td></tr>
<tr><td>Date Conducted</td><td colspan="10"></td></tr>
<tr><th colspan="11">Technical Information</th></tr>
<tr><th colspan="11">Description of Transaction Selection</th></tr>
<tr><td colspan="11"></td></tr>
<tr><th colspan="11">Assessment Criteria - (tick all that applies)</th></tr>
<tr><th>Single or List of Transactions</th><th>Manual/ Paper-based</th><th>Critical</th><th>Costly</th><th>Frequent</th><th>Liklihood of Mgt.</th><th>Complex</th><th>Contractual Requirement</th><th>Regulatory Requirement</th><th>Total Score</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Figure 7-4 Assess needs—sample form

Each criterion is kept subjective, so that users have the flexibility to identify transactions for IT improvement in accordance with their specific environment and context. Use of criteria is kept simple through clicking the criterion that applies during the transaction identification and selection. A total score is calculated by simply adding the number of criteria that apply to each transaction, with higher scores indicating that the transaction more fully meets the defined criteria. This is intended only to provide some guidance to the user, who can take broader issues into consideration to choose the highest priority transaction.

7.6.2 Step 2—Define the As-is Transaction Map

Once a transaction is identified for IT improvements, the next step is to define the As-is transaction map (As-is TM). The term “As-is” refers to the way communication is taking place between the parties currently. Use case and expert interview approaches can be used to define the As-is TM. To define the As-is TM, a form was developed as shown in Figure 7-5 that has the following two sections:

General administrative information—includes the following information related to TM and transaction development personnel: *name* (Appendix J, Section J.1.1), a globally unique *identifier, change log, developer’s email address* (used as an identifier), and *status* (new TM or revision).

Technical information—includes; the definition, purpose, scope, specification, graphical representation, and As-is performance of the As-is TM.

As-is transaction map definition, purpose, and scope—captures the *definition (*brief description), *purpose* (core objective), and *scope (*transaction operational boundaries*)* of a transaction.

Step - 2 Define As-is Transaction Map							
General Administrative Information							
Name							
Identifier							
Change Log	**Date**		**Status**			**E-mail**	
Technical Informtion							
As-is transaction map definition, purpose, and scope:							
As-is Transaction Map Specification							
Name of Atomic Transaction			**From**		**To**		**Mode of Communication**
Generic Name	**Specific Name**		**Designation**	**Organization**	**Designation**	**Organization**	
Graphical Representation							
This space is reserved for hand-written sequence diagrams that are to be created based on As-is transaction map specification. Later these diagrams are to be tranformed to a formal sequence diagram using UML or any business process modelling application.							
As-is Transaction Performance Criteria							
Time (person-hrs)	**Rate**	**Cost ($)**		**Rate**	**Quality**		**Rate**
Transaction formulation time		**Transaction formulation cost**			**Level of message interpretability**		
Transaction transmission time		**Transaction transmission cost**			**Level of message structuring**		
					Ease of handling, tracking & retrieval		

Note: Rating criteria is "H" for high, "M" for medium, "L" for low, and "N" for non or not at all easy or not applicable

Figure 7-5 Define As-is transaction map—sample form

As-is TM specification—identifies and defines the number and sequence of atomic transactions (single communications between parties) in a given TM. The TM specification includes: *generic name of atomic transaction*, *specific name of atomic transaction* (named based on naming rules described in Appendix J, Section J.1.1), *from, to* and *mode of communication (*E-mail, telephone, fax, postal mail, etc). Capturing information about communication mode is optional; however, it gives an idea about the way information is currently exchanged between the parties.

Graphical representation—provides a representation of the transaction specification information (i.e. atomic transaction, from, to) in a graphical form.

As-is transaction performance—captures transaction performance based on three factors time, cost, and quality. *Time (person-hours)*—measures transaction efficiency in terms of formulation time (time required to create messages) and transmission time (time required to transmit messages). *Cost ($)*—measures transaction cost in terms of formulation cost (spent on creating messages) and transmission cost (spent on transmitting messages). *Quality*—measures transaction effectiveness in terms of message interpretability; message structuring; and ease of handling, tracking, and retrieving a message. All of these factors provide aids to time and cost savings. For instance, if a message is more computer-interpretable and structured, it's processing and analysis time is reduced due to lessening the chances of errors in filling and reading the message information, which leads to time and cost savings. These are indirect benefits and it is very difficult to measure them. Therefore, a subjective rating criterion of high (H), medium (M), low (L), and none/not at all easy/not applicable (N) was developed to measure them. On the rating continuum, "H" represents a positive and "L" shows a negative measure of the quality based performance criteria. A vice-versa criterion is true for the time and cost-based performance criteria. Documenting As-is transaction performance is kept simple and optional because of the non-availability of the objective performance data, and difficulty to determine or get access to such data, if available. Using these rating criteria, the As-is transaction performance is benchmarked through establishing performance targets for the To-be transactions.

7.6.3 Step 3—Develop the To-be Transaction Map

The To-be TM is developed based on the As-is TM defined in the earlier step. The To-be TM is the improved or proposed way of conducting the As-is communication. As shown in Figure 7-6, a form is developed to assist the transaction development personnel to transform the As-is TMs into To-be TMs.

This form is slightly different from the one created in the previous step (i.e. define As-is TM), so the fields have the same definitions, except for the following two:

Summary of proposed improvements—briefly describes the changes or improvements proposed in relation to process, information, and mode improvements.

Proposed improvements—are the modifications proposed in the As-is TM. Improvements; if any, are documented for each atomic transaction in terms of the process, information, and mode improvement. The *process improvement* relates to adding or deleting atomic transactions from the As-is TM to satisfy new requirements. In other words, process improvements focus on improving the way As-is TM is currently practiced. The *information improvement* modifies the way information is currently exchanged between the parties in terms of structuring and formalizing information (i.e. how structured and computer-interpretable is the information?). The *mode improvement* alters the mode or channel through which the transaction is currently accomplished in order to enhance the efficiency and effectiveness of the communication. A check mark (√) is applied for each improvement that applies while formalizing a given atomic transaction. The *description of the proposed improvements* summarizes modifications or improvements of all the three kinds that apply to a given atomic transaction to describe it more clearly at a finer level of granularity.

Step - 3 Develop To-be Transaction Map			
General Administrative Information			
Name	$tm_{to\text{-}be}$_tca_reporting		
Identifier			
Change Log	**Date (dd/mm/yy)**	**Status**	**E-mail**
Technical Informtion			
Summary of Proposed Improvements:			

To-be Transaction Map Specification									
Name of Atomic Transaction		**From**		**To**		**Proposed Improvements**			
Generic Name	**Specific Name**	**Designation**	**Organization**	**Designation**	**Organization**	**Process Improv.**	**Infor. Improv.**	**Mode Improv.**	**Description of Proposed Improvements**

Graphical Representation
Two formal sequence diagrams are created in UML for the To-be transaction map specification mentioned above using the generic and specifc names from general user and develper perspective.

To-be Transaction Performance Criteria					
Time (person-hrs)	**Rate**	**Cost ($)**	**Rate**	**Quality**	**Rate**
Transaction formulation time		**Transaction formulation cost**		**Level of message interpretability**	
Transaction transmission time		**Transaction transmission cost**		**Level of message structuring**	
				Ease of handling, tracking & retrieval	

Note: Rating criteria is "H" for high, "M" for medium, "L" for low, and "N" for non or not at all easy or not applicable

Figure 7-6 Develop To-be transaction map—sample form

7.6.4 Step 4—Collect Information

Information is collected for each atomic transaction of the To-be TM defined in Step 3. The collected information is to be represented in a message that is exchanged between the parties in an atomic transaction. A message represents two types of information: header and payload information. A form is developed to collect header information as shown in Figure 7-7 and is divided into two sections.

7.6.4.1 Header Information

7.6.4.1.1 Specification of Header Information

The *header information* is the meta information about the transaction and message. The header information specification section defines the following header information that are to be represented in a message template:

Name of atomic transactions, (To-be) TM—is the name of the atomic transaction identified in the To-be TM based on the naming rules defined for the proposed TFP (Appendix J, Section J.1.1).

Rank header information—represents the level to which an information is required in a given transaction or message based on a three-point requirement continuum: required, optional, and not applicable. Information ranking is important from a user perspective as different users have different requirements in different transactions.

Step - 4 Collect Information																		
Specification of Header Information																		
Name of Atomic Transaction, (To-be Transaction Map)	Rank Header Info.	Preamble Header Info.	Delivery Header Info.										Service Header Info.					
		Reference Info.	Actor Info.	Actor Role Info.		Temporal Info.						Security Info.	Transaction General Info.				Message General	
		Header Information Attributes - NOTE: Apply tick "√" all that applies																
		Data Model/ Ontology Version	Name/Address/ Fax/Tel	Role TrackingID	Sender/Receiver Role	Transaction Duration	Transaction Start/End Date	Message Duration	Receipt/Accept Signal Duration	Respond to Action Duration	Message Sent/ Receivd Data	High/Medium/ Low	Transaction Name	Transaction Purpose	Transaction Definition	Transaction Affiliation	Message Purpose	Message Definition
	REQ																	
	OPT																	
	N/A																	
Specification of Location Specific Header Information; if any.																		
Name of Atomic Transaction, (To-be Transaction Map)	Rank Header Info.	Preamble Header Info.	Delivery Header Info.										Service Header Info.					
		Header Information Attributes - NOTE: Apply tick "√" all that applies																
	REQ																	
	OPT																	
	N/A																	

Figure 7-7 Collect header information—sample form

A set of the most common header information is pre-identified and defined based on three categories: preamble, delivery, and service header information, to ease the process of header information specification and enhance user's understanding of the terms used.

Preamble header information—is a mandatory header that relates to the reference information about the data model or ontology upon which the messages are developed. *Reference information*—represents the version of the data model or ontology upon which a message is designed. This information is important from a software developer perspective and is not to be represented in the MTs, but rather is kept as reference information so as to track which version of the data model the MT is based on.

Delivery header information—is a mandatory header representing actor, actor-role, temporal, and security information. *Actor information*—includes information related to individuals and organizations involved in a transaction, e.g. name, E-mail, fax, and telephone number. *Actor role information*—pertains to the different roles an actor play in a given transaction. The attributes of the actor role information are: role tracking ID and sender/receiver role. This information is important from the developer's perspective and is not required to be represented in a message template. *Temporal information*—represents time-related information about a message and transaction, e.g. transaction duration, message duration, etc. A complete set of time-related temporal information is presented in Figure 7-7. *Security information*—

captures the level of security (e.g. high, medium, and low) required in a given transaction for the secured transport of the information. This information is important from a developer perspective and need not be represented in the header section of the MT, it can only be used while designing secured transport protocols for the exchange of MTs.

Service header information—is a mandatory header representing general information about the transaction and message. *Transaction general information*—represents general information like name, purpose, definition, and affiliation of the transaction. *Message general information*—captures general information like the purpose and definition of a message that is exchanged in an atomic transaction between the parties. This information is important from the developer's perspective, but is not important from the general user perspective; therefore, this information need not be represented in the header section of the MT.

7.6.4.1.2 Specification of Location Specific Header Information

The header information discussed above is generic while users may need additional location-specific requirements that can be documented under the location specific header information section of the form presented in Figure 7-7.

7.6.4.2 Payload Information

7.6.4.2.1 Specification of Payload Information

The *payload information* is the actual information content that parties exchange in order to accomplish a transaction successfully. This information is to be identified and defined for each atomic transaction. To specify this information, a form was developed as shown in Figure 7-8. Various elements of the form are described as follows:

Step - 4 Collect Information																	
Specification of Payload Information																	
Name of Atomic Transaction, (To-be Transaction Map)	**Payload Information**	**Rank Payload Information**			**Attribute(s) of Payload Information**												
	Description	**REQ**	**OPT**	**N/A**													
Location Specific Payload Information; if any.																	
Name of Atomic Transaction, (To-be Transaction Map)	**Payload Information**	**Rank Payload Information**			**Attribute(s) of Payload Information**												
	Description	**REQ**	**OPT**	**N/A**													

Figure 7-8 Collect payload information—sample form

Name of atomic transaction, (To-be TM), and rank payload information—are defined above and their definitions remains the same.

Payload information description—represents the details of the information content in plain English that the parties need to exchange in a given transaction.

Payload information attributes—are the characteristics that describe the payload information. To use the form, the payload information is to be defined for each atomic transaction under the description column. Each piece of information is to be ranked based on the requirements of the general users through applying a check mark (√). For each piece of the information, attributes are to be identified and defined as per the user's requirements.

7.6.4.2.2 Location Specific Payload Information

The *location specific payload information* represents the additional payload information that the users need in transactions that are conducted in specific locations. A location can be a place, project, sector, or industry to which a transaction belongs.

7.6.5 Step 5—Design Message Template

The message templates (MTs) are designed based on the header and payload information collected in the Step 4. This information is represented in the MT in a well-structured and computer interpretable format that is exchanged between the parties in atomic transactions. No specific form is developed for this step; however, general guidance is presented on how to formulate a well-structured and computer-interpretable MT for an application area.

To achieve message-based interoperability between information systems of the infrastructure organizations, the MTs should represent the header and payload information in a computer interpretable format, i.e. the information is to be captured from an information model or ontology. The transaction development personnel are not restricted to use a specific information model or ontology; rather they have the choice to use any ontology that best supports the design of the MTs in a specific application area. In this research work, the MTs were defined for the AI&CAR/TCA Reporting, in which the header information was captured from the Transaction Domain Ontology, (Zeb and Froese, 2012) and the payload information was captured from the Tangible Capital Asset Ontology (Zeb and Froese, 2013).

A set of tools and techniques are available to define message templates; however, in this research work, Microsoft InfoPath was used to define MTs for the AI&CAR/TCA Reporting due to low cost, ease of use and availability. The formalized MTs are then implemented in the web-based applications for the exchange of information in each atomic transaction between different parties.

7.6.6 Step 6—Review To-be Transaction Map and Message Template

It is important to review the To-be TM and formalized MTs prior to implementing it into a web-based collaboration systems. The transaction development personnel should carry out the review process in joint consultation with industry experts. The aim of the review is to identify shortcomings and propose modifications; if any, to accurately represent industry requirements. A review form is developed as shown in Figure 7-9. It has two sections: general administrative information and technical information section.

General administrative information—captures general information about the review process, which includes the name of the TM, date reviewed, and change log (i.e. review version).

<table>
<tr><th colspan="11">Step - 6 Review Transaction Map and Message Template</th></tr>
<tr><th colspan="11">General Admin Information</th></tr>
<tr><td>Name of TM</td><td colspan="10"></td></tr>
<tr><td>Date Reviewed</td><td colspan="10"></td></tr>
<tr><td>Change Log</td><td colspan="10"></td></tr>
<tr><th colspan="11">Technical Information</th></tr>
<tr><td colspan="11">Summary Information:</td></tr>
<tr><td colspan="11"></td></tr>
<tr><td colspan="11">Review of To-be Tranasaction Map
NOTE: Apply "√" for Yes and "x" for No in the change required column</td></tr>
<tr><td>Name of
Atomic Transaction</td><td>Change
Req.</td><td colspan="9">Description of Proposed Changes, if any.</td></tr>
<tr><td></td><td></td><td colspan="9"></td></tr>
<tr><td colspan="11">Review of Message Templates
NOTE: Apply "√" for Compliance, "x" Non-Compliance, and "-" for Not Applicable</td></tr>
<tr><td rowspan="2">Name of Atomic
Transaction</td><td>Sender
Role</td><td>Receiver
Role</td><td>Formatting
Req.</td><td colspan="7">Context Req.</td></tr>
<tr><td>From</td><td>To</td><td>Design
Req.</td><td>Location
Req.</td><td>Contractual
Req.</td><td>Exchange
Req.</td><td>Regulatory
Req.</td><td>Security
Req.</td><td>To-be Transaction
Performance</td><td>Others;
if any.</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="11">Proposed Changes/Revisions, if any.</td></tr>
<tr><td colspan="11"></td></tr>
</table>

Figure 7-9 Review To-be transaction map and message templates—sample form

Technical information—includes summary information, review of To-be TM and MTs, and description of revisions.

Summary information—represents a comprehensive overview of the proposed changes in the To-be TM and MTs. The summary information provides a snapshot of the entire proposed changes.

Review of To-be TM—refers to reviewing the process of information exchange. The main emphasis is to examine the requirements for the addition, deletion, or keeping atomic transactions As-is before adopting and implementing them in software applications. The review process starts with listing each atomic transaction of the To-be TM under the *name of atomic transaction* and then it is discussed with industry experts one by one to determine which ones are required or otherwise. The *description of the proposed modifications* documents the decisions made about adding, replacing, deleting or keeping a specific atomic transaction As-is in the overall information exchange process.

Review of message templates—examines compliance of the defined MTs with the information formatting requirement and context requirement. The *information formatting requirement* reviews the design and outlook of the information represented in the MT. The *information context requirement* focuses on the accuracy and completeness of the information represented in a MT in terms of the compliance with the requirements including: location, contractual, exchange, regulatory, security, To-be transaction performance, and others; if any requirements.

Description of changes/revision; if any—represents a brief description of the changes proposed in the defined MTs.

Upon completion of the review, all of the key deliverables that describe the proposed transaction are finalized and assembled into a *formal transaction specification* that includes the final To-be TM, the content and format of the final MTs, the identified actor-roles, and all the forms that are filled with the required information towards finalization of the TM and MTs. The review of the To-be TM and MTs can be accomplished through an expert interview survey approach where the experts are provided with the review form through a questionnaire. A questionnaire (attached at Appendix N) was developed for the review of the To-be TM and MTs defined for the AI&CAR/TCA Reporting.

7.6.7 Step 7—Adopt and Implement the Transaction Specification

Once the review is completed and the transaction specification is finalized, it is then implemented in software applications. No specific form is developed for this step, but rather some guidance is provided on how to implement these transaction specifications in collaboration systems. The transaction development personnel either adopt already developed transaction specifications by other parties or develop their own specifications. Whatever the mode of adoption is, it is to be implemented in web-based applications to enable collaboration of different parties. Implementation of transaction specifications ranges from a simple case, e.g. a data set exchanged in the form of a spreadsheet file transmitted as an email attachment, to a complex case where custom software applications are developed to implement transaction specifications. A pilot solution was proposed in this research work that falls between these two extremes. The pilot solution was developed for AI&CAR/TCA Reporting between the municipal and provincial government. In the proposed pilot solution as described in Chapter 9, the transaction specification was implemented as a workflow process using a set of applications: MS InfoPath Filler, MS SharePoint, MS Sharepoint Form Services, MS Outlook, MS Exchange, and MS SharePoint Excel Services.

7.6.8 Step 8—Monitor Transaction Specification

The monitoring of transaction specification is important from a continuous-improvement perspective. A form was developed to monitor transaction specifications as shown in Figure 7-10. The transaction specifications that were already developed and implemented in software applications should be monitored for continuous improvement due to dynamic nature of the AEC/FM industry. The form is divided into two sections representing administrative information (defined previously) and technical information about the overall improvements proposed in the TM and MTs. A brief description of the technical information follows:

Summary of proposed improvements—captures a comprehensive and concise description of the improvements proposed in the TM and MTs.

Monitor transaction map—reviews the process of communication between different collaboration partners. This review suggests whether an atomic transaction is to be kept, replaced or deleted from a TM.

Monitor To-be transaction performance—reviews and measure performance of the To-be TM. The TM performance is measured based on three criteria: time, cost, and quality as explained previously.

Monitor message templates—reviews the header and payload information represented in the individual MT developed for each atomic transaction. The payload and header information is reviewed for formatting and context requirements.

Monitor message template performance—reviews performance of the MTs based on time, cost, and quality criteria.

Description of the proposed improvement for MTs—describes briefly the improvements proposed to the MTs.

<table>
<tr><th colspan="10">Step - 8 MonitorTransaction Agreement - (Transaction Map and Message Templates)</th></tr>
<tr><th colspan="10">General Administrative Information</th></tr>
<tr><td>Name of TM</td><td colspan="9"></td></tr>
<tr><td>Date Monitored</td><td colspan="9"></td></tr>
<tr><th colspan="10">Technical Information</th></tr>
<tr><td colspan="10">Summary of Proposed Improvements:</td></tr>
<tr><td colspan="10"></td></tr>
<tr><td colspan="10">Monitor Tranasaction Map
NOTE: Apply "√" for Yes and "x" for No under Improvement Required Column</td></tr>
<tr><th>Name of Atomic Transaction</th><th>Imrovement Requirement</th><th colspan="8">Description of Proposed Improvement, if any.</th></tr>
<tr><td></td><td></td><td colspan="8"></td></tr>
<tr><td colspan="10">Monitor To-be Transaction Performance (NOTE: Rating criteria is "H" for High, "M" for Medium, "L" for Low, and "N" for Non or Not at All Easy or Not Applicable)</td></tr>
<tr><th>Time (person-hrs)</th><th>Rating</th><th colspan="3">Cost ($)</th><th>Rating</th><th colspan="3">Quality</th><th>Rating</th></tr>
<tr><td>Transaction formulation time</td><td></td><td colspan="3">Transaction formulation cost</td><td></td><td colspan="3">Ease of handling</td><td></td></tr>
<tr><td>Transaction transmission time</td><td></td><td colspan="3">Transaction transmission cost</td><td></td><td colspan="3">Add other, if any</td><td></td></tr>
<tr><td>Add other, if any</td><td></td><td colspan="3">Add other, if any</td><td></td><td colspan="3"></td><td></td></tr>
<tr><td colspan="10">Monitor Message Templates (NOTE: Apply "√" for Compliance, "x" Non-Compliance, and "-" for Not Applicable under the Formatting & Context Req. Columns)</td></tr>
<tr><th rowspan="2">Name of Atomic Transaction</th><th>Sender</th><th>Receiver</th><th>Formatting Req.</th><th colspan="6">Context Requirement</th></tr>
<tr><th>From</th><th>To</th><th>Design Req.</th><th>Location Req.</th><th>Contrac-tual Req.</th><th>Exchange Req.</th><th>Regulatory Req.</th><th>Security Req.</th><th>Others; If any.</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="10">Monitor Message Template Performance (NOTE: Rating criteria is "H" for High, "M" for Medium, "L" for Low, and "N" for Non or Not at All Easy or Not Applicable</td></tr>
<tr><th>Time (person-hrs)</th><th>Rating</th><th colspan="3">Cost ($)</th><th>Rating</th><th colspan="3">Quality</th><th>Rating</th></tr>
<tr><td>Message formulation time</td><td></td><td colspan="3">Message formulation cost</td><td></td><td colspan="3">Ease of handling and navigation</td><td></td></tr>
<tr><td>Message transmission time</td><td></td><td colspan="3">Message transmission cost</td><td></td><td colspan="3">Ease of tracking and retreival</td><td></td></tr>
<tr><td>Add other, if any</td><td></td><td colspan="3">Add other, if any</td><td></td><td colspan="3">Add other, if any</td><td></td></tr>
<tr><td colspan="10">Description of Proposed Improvements for message templates, if any.</td></tr>
<tr><td colspan="10"></td></tr>
</table>

Figure 7-10 Monitor transaction specification—sample form

7.7 TFP Tool Application in the Domain of Infrastructure Management

The TFP Tool was applied in the domain of infrastructure management by using to formalize the AI&CAR/TCA Reporting transaction. In this process, the municipal government reports the Tangible Capital Asset (TCA) information to the provincial government for financial planning and budget allocations. There are some issues with this process; (i) presently, the TCA reports are sent as a word or PDF document attached to an E-mail, which needs human interpretation at the receiving end, thus making the whole process prone to errors; (ii) the TCA reports are generated in different data formats that make it difficult and time-consuming to extract and compile data manually; and (iii) the reports generated from various municipalities differ in definition and grouping of assets into various categories, making interpretation of data difficult. The proposed TFP Tool was used to formalize the AI&CAR/TCA Reporting process, which was implemented in a prototype AIIS, which collects, integrates, and analyzes the asset information received from different municipalities.

While formalizing the AI&CAR/TCA Reporting process, all the forms of the proposed TFP tool were filled using a case study and expert interview approaches. In this chapter, only the “develop To-be TM form” for the AI&CAR/TCA Reporting is presented in Figure 7-11 as a sample. The To-be TM developed for the AI&CAR/TCA Reporting consists of ten atomic transactions (Appendix K, Section K.1.3, Figure K-5); however, only three atomic transactions are shown in Figure 7-11 due to reduce space. The defined To-be TM for the AI&CAR TCA Reporting was transformed into graphical representation using a UML sequence diagram (Appendix K, Section K.1.3, Figure K-6 and Figure K-7) for clarity and ease of understanding.

Step - 3 Develop To-be Transaction Map			
General Administrative Information			
Name	tm_{to-be}_tca_reporting		
Identifier			
Change Log	**Date (dd/mm/yy)**	**Status**	**E-mail**
	5/30/2012	Created	xyz@interchange.ubc.ca
Technical Informtion			

Summary of Proposed Improvements:

The following is a brief summary of the improvements proposed to the As-is TM.
i. **Process improvement** - the As-is communication process is to be modified for some transactions to tranform it from one/two action with no acknowledgement to one/two action with acknowledgement transactions.
ii. **Information improvement -** it is proposed that the TCA information is to be defined and well structured in a message form as part of the atomic transaction so that it can be interpretable by the receiving system.
iii. **Mode improvements** - current modes of communication adopted for TCA information is to be transformed with an efficient and effective mode of communication - message template based exchange of information through a web-based system.

To-be Transaction Map Specification

Name of Atomic Transaction		**From**		**To**		**Proposed Improvements**			
Generic Name	**Specific Name**	**Designation**	**Organization**	**Designation**	**Organization**	**Process Improv.**	**Infor. Improv.**	**Mode Improv.**	**Description of Proposed Improv.**
request tca information	tm_{to-be}_tca_atom$_1$_ request_tca info.	Mgr. Finance	Municipality	Mgr. Engg.	Municipality		√	√	Information is to be defined & communication mode is to be changed from E-mail/Server/Tel/ CD/Post-mail to template based exchange.
receipt acknowledgement tca information	tm_{to-be}_tca_atom3_ receipt_ ackow._tca info.	Co-ord. Engg.	Consultant	Mgr. Engg.	Municipality	√	√	√	Ditto In addition to above, process is to be improved.
accept acknowledgement tca information	tm_{to-be}_tca_atom5_ accept_ ackow._tca info.	Mgr. Engg.	Municipality	Co-ord. Engg.	Consultant	√	√	√	Ditto In addition to above, process is to be improved.
receipt acknowledgement tca information	tm_{to-be}_tca_atom10_ receipt_ acknow_tca info.	Asset Co-ord.	Prov. Govt.	Mgr. Finance	Municipality	√	√	√	Ditto In addition to above, process is to be improved.

Graphical Representation

Two formal sequence diagrams are created in UML for the To-be Transaction Map specification mentioned above using the generic and specifc names from general user and developer perspective.

To-be Transaction Performance Criteria

Time (person-hrs)	**Rate**	**Cost ($)**	**Rate**	**Quality**	**Rate**
Transaction formulation time	L	**Transaction formulation cost**	L	**Level of message interpretability**	H
Transaction transmission time	L	**Transaction transmission cost**	L	**Level of message structuring**	H
				Ease of handling, tracking & retrieval	H

Note: Rating criteria is "H" for high, "M" for medium, "L" for low, and "N" for non or not at all easy or not applicable

Figure 7-11 Develop To-be transaction map for asset inventory and condition assessment reporting/ tangible capital asset reporting

As part of the transaction specification developed for the AI&CAR/TCA Reporting, the complete set of forms was filled in step 1—assess needs (Appendix K, Section K.1.1, Figure K-1), step 2—define As-is TM (Appendix K, Section

K.1.2, Figure K-2), step 3—develop To-be TM (Appendix K, Section K.1.3, Figure K-5), step 4—collect information (Appendix K, Section K.1.4, Figure K-8 and Figure K-9), step 6—review TM/MT (Appendix K, Section K.1.6, Figure K-28). The form developed for step 8—monitor transaction specification (Chapter 7, Section 7.6.8, Figure 7-10), was not yet filled because it will be used after the implementation of the AI&CAR/TCA Reporting specification. Some guidance is presented for step 5—design MT (Appendix K, Section K.1.5, Figure K-10 to Figure Figure K-27) and step 7—implement TM/MT (Appendix K, Section K.1.7).

7.8 Transaction Formalism Protocol Evaluation

The proposed TFP Tool was validated through industry experts using a framework presented in Table 7-1. The framework shows a set of criteria, measures, and tests in terms of the questions. Adesola and Baines (2005) identified three criteria: feasibility, usability, and usefulness to validate an improvement methodology, which were adopted with modifications to validate the proposed TFP Tool. An additional criterion—generalizability—was also identified, defined, and used to validate the TFP Tool.

Table 7-1 Transaction formalism protocol tool validation

	Transaction Formalism Protocol Tool Evaluation	
Criteria	**Measures**	**Tests - How to achieve a measure?**
Feasibility	Completeness	Does the TFP tool incorporate all the steps required for the design/improvement, implementation, and management of transactions?
	Correctness	Are the steps of the TFP tool right?
	Reasonableness	Are the steps of theTFP tool reasonable?
Usability	Understandability	Is the TFP tool easy to understand?
	Applicability	Is the TFP tool easy to apply while defining transactions?
	Guidance/ Supportability	Does the TFP tool provide sufficient guidance on how to fill various sections of forms?
Usefulness	Effectiveness	Do you feel that the use of the TFP tool produce useful and effective results?
	Efficiency	Does the use of the TFP tool save you time and cost compared to defining transactions without using the proposed TFP tool?
	Consistency	Does the use of the TFP tool result in the creation of consistent transactions that are easily implementable in a variety of applications?
	Changeability/ Adaptability	Does the use of the TFP tool result in the creation of transactions that are easily modifiable with changing requirements?
	Reusability	Does the use of the TFP tool result in the creation/development of reuseable transactions?
Generalizeability	Generality	Is the proposed TFP applicable to formalize diverse communications in the AEC/FM and non-AEC/FM industries?

Feasibility assesses the appropriateness of the TFP Tool in terms of completeness, correctness, and reasonableness. *Usability* assesses the ability to learn and work with the TFP Tool, which was evaluated using three measures: understandability, applicability, and guidance/supportability. *Usefulness* assesses the utility and value of the tool in terms of five measures: effectiveness, efficiency, consistency, changeability/adaptability/customizability, and reusability. Finally, *generalizability* assesses the applicability of the tool across a wide variety of communications within AEC/FM and non-AEC/FM industries, using a single measure of generality. These metrics and associated test questions are shown in Table 7-1.

The TFP Tool was validated using an expert interview approach. The TFP Tool was presented to the experts through a questionnaire (attached at Appendix O) developed as part of this research work. The experts were transaction analysts, process modelers, and industry experts in the domain of infrastructure management. The expert interview composed of three sessions. In the *introduction session,* the proposed TFP Tool was introduced. In the *comprehension session,* the content represented in all the forms of the proposed TFP Tool was reviewed to give the experts a clear understanding of the content. In the *execution session*, experts examined the forms completed for the AI&CAR/TCA Reporting process and answered all the questions shown in Table 7-1. The experts answers were recorded on an agreement continuum rating system: unable to rate (0), strongly disagree (1), disagree (2), neither agree nor disagree (3), agree (4), and strongly agree (5).

The expert review data for each of the criteria of feasibility (Appendix M, Section M.1.3, Table M-3), useability (Appendix M, Section M.1.4, Table M-5), usefulness (Appendix M, Section M.1.5, Table M-7), and generalizability (Appendix M, Section M.1.6, Table M-9), was recorded against each question (i.e. measure) and an average score was calculated. The resulting average scores ranged from 4 (agree) to 4.8~5 (strongly agree), indicating that the proposed TFP tool was feasible, usable, useful, and generic. The expert review data were also tested for statistical significance using ANOVA two-factor without replication technique. The statistical analysis was carried out using a confidence level of 95% and alpha (α) factor of 0.05. The null hypothesis states that there is no statistical significance between the responses recorded by different respondents for feasibility (Appendix M, Section M.1.3, Table M-4), usability (Appendix M, Section M.1.4, Table M-6), and usefulness (Appendix M, Section M.1.5, Table M-8). The results of the statistical analysis indicate that the null hypothesis is to be accepted and that there is a universal agreement of the respondents (experts) on the feasibility, usability, and usefulness of the TFP Tool.

7.9 Conclusions

In the domain of infrastructure management, there is a trend to transform the current practice of manual data exchange towards a more formalized computer-to-computer data exchange (known as a transaction). Presently, there exist some methodologies and standards within AEC/FM and other industries to formalize the work process and computer-based communications; however, these don't completely support the design, implementation, and management of transactions in the domain of infrastructure management. These standards are mostly process-centric and support 3D object-based data exchange in comparison to message-based exchange of information. Also, these methodologies lack a step-by-step procedure that transaction development personnel can easily apply. The proposed protocol was developed to address these issues.

The proposed TFP is an eight-step procedure developed using a four-step methodology: identify and select existing standards, benchmark existing standards, link and build on existing standards, and develop the proposed TFP. The protocol was developed from two perspectives: TFP Specification and TFP Tool. The TFP specification represents a conceptual framework that models each step of the protocol as a distinct function for which inputs, controls, mechanisms, tool/techniques, and outputs were defined using the IDEF0 functional modeling technique. On the other hand, the TFP Tool was created from the application perspective and it consists of a set of forms and guidance developed for each step of the protocol. In step 1, needs assessment is conducted, step 2 and 3 define the As-is and To-be TMs in an application area, step 4 collects the header and payload information from the experts, step 5 defines the MT based on the collected header and payload information, step 6 reviews the formalized To-be TM and MTs (transaction specification), step 7 implements the specification in software applications, and step 8 monitors the implemented specification for improvements over the life cycle of transactions.

The TFP Tool was applied in the domain of infrastructure management to formalize the AI&CAR/TCA Reporting. This formalized transaction specification was implemented in a prototype system—AIIS to enable the municipal government (i.e. municipalities) to report TCA information to the provincial government effectively and efficiently.

The TFP Tool was validated using four criteria: feasibility, usability, usefulness, and generalizability. The results of the validation indicate that the protocol tool was feasible, usable, useful, and generic. It is recommended that the proposed TFP needs to be further tested to formalize diverse communication in various application domains or industries to monitor it’s validity and generalization. The complete transaction formalization cycle duration also needs to be explored and examined to objectively check effectiveness and efficiency of the proposed TFP Tool application. In addition, a framework of transaction maturity needs to be developed to embed the transaction development personnel skills into the protocol to reflect skill and knowledge competence. This would help in tailoring user’s skill sets with each step of the TFP Tool. Moreover, it would be more beneficial if the proposed TFP Tool is to be implemented in an interactive web-based application. This would help in creating transaction specifications automatically while also improve self-learning and communication between the transaction development personnel.

Chapter 8 Infrastructure Transaction Management Portal

8.1 Introduction

The research question "how to formalize and manage transaction?" has two parts: "how to formalize transactions?" and "how to manage transactions?" The first part of question was dealt with developing an ontology-supported Transaction Formalism Protocol (TFP) and the solution to the second part of the question was proposed in terms of developing an Infrastructure Transaction Management Portal (ITMP)—Objective 4 (b), which is the main focus of this chapter. The work presented previously in this dissertation describes the issue of formalized transactions within the infrastructure management sector, presented ontologies—Objective 2 (a and b) (see Chapter 4 and 5) that model the concepts and information that make up transactions, and discussed a TFP Specification and Tool—Objective 3 (a and b) (see Chapter 6 and 7) that can be used to create formal transaction specifications. If an infrastructure organization uses these techniques to define its information transactions, then it will also need: (i) an approach to collect and work with (i.e. to manage) these transaction specifications; and (ii) ways of implementing these transactions to carry out individual information exchanges.

This chapter[8] consists of seven sections that address the first of these remaining two steps by describing the development of a tool for managing transaction specifications (i.e. ITMP)—Objective 4 (b). The following Chapter 9 addresses the second step by describing a tool that implements the transaction specifications in the Asset Information Integrator System (AIIS)—Objective 4 (c). This chapter describes the architecture, detailed development, and functionalities of the proposed ITMP. The development of the ITMP was based on the knowledge represented in the Transaction Domain Ontology (Trans_Dom_Onto). A transaction specification developed for Asset Inventory and Condition Assessment/Tangible Capital Asset (AI&CAR/TCA) Reporting was used to demonstrate the approach to be used by the transaction development personnel for transaction specification management (i.e. archiving transaction specification). The ITMP functionalities and limitations and challenges are presented towards the end of the chapter.

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[8] A version of this chapter is submitted for publication.

Zeb, J. and Froese, T. (2014). "An Ontology-Supported Infrastructure Transaction Management Portal", Journal Manuscript Submitted for Publication.

8.2 Related Research Work

A literature review first surveyed related state-of-the-art standards and methodologies in the non-AEC/FM and AEC/FM industries to identify gaps and establish the points of departure, and second, assessed existing ontologies in the domain of transaction design and management to justify the use of the Trans_Dom_Onto for developing the ITMP.

The primary references with regards to standards and methodologies that led to the development of the portal includes: Open Electronic Data Interchange, Open-EDI (ISO, 1995), United Nation's Centre for Trade Facilitation and Electronic Business (UN/CEFACT) Modeling Methodology, UMM (UN/CEFACT, 2003), Electronic Business Extensible Markup Language, ebXML (ISO, 2004-05), RosettaNet (Damodaran, 2004), Associated General Contractors of America Extensible Markup Language (Zhu, 2007), Information Delivery Manual, IDM (IAI-IDM, 2007 and IAI-IDM, 2012), Model View Definition, MVD (IAI-MVD, 2005), VISI (VISI, 2007 and VISI, 2011), COINS Engineering Method, CEM (Schaap *et al.* 2008). Detailed analysis of these references is given in Chapter 1, Section 1.4.4.

Similarly, related ontologies were studied to justify the use of Trans_Dom_onto for the development of the proposed ITMP. These ontologies were: Open-Electronic Data Interchange Transaction Ontology, Open-edi Onto (ISO, 2006) Resource-Event-Agent Ontology, REA-Onto (Allen and March, 2006), and Infrastructure and Construction Process Ontology, IC-Pro-Onto (El-Gohary, 2008). Detailed discussion of these ontologies is given in Chapter 1, Section 1.4.3.

8.3 Proposed Approach

When information is exchanged through human-to-human communications (whether it is face-to-face or through paper or electronic documents), there is no need for a formal specification to prescribe the detailed process and content of the exchange. The context of this research, however, addresses the trend towards computer-to-computer information exchange, which do need to be formally designed and agreed upon between the sending and receiving parties. As introduced earlier, this can be achieved through the process of creating formal transaction specifications. Elsewhere, we have addressed several facets of this process: ontologies that formally model the required information (Zeb and Froese, 2012), a protocol that defines the design steps (Zeb and Froese, 2013), and a tool that supports the creation of individual specifications.

As computer-to-computer information becomes increasingly the norm, a transaction specification could proliferate, developed by many different parties at many different levels for many different audiences. For example, transaction development personnel (including; transaction analysts, transaction designers, transaction modellers, software developers and industry experts) could develop transaction specification standards (create new or adapt existing standards) at each of the following four levels:

- Industry level—transaction specifications can be developed and approved by a relevant authority to be used as optional or regulated industry standards. These are generic industry-specific transaction specifications that are independent of the organization, project, or user requirements and can be used across the industry.

- Organization level—individual companies may develop transaction specifications that align with corporate objectives and practices, for use both with internal communications and external transactions along their supply chains.
- Project level—since infrastructure projects bring together large teams of people from many different companies on large scale ventures, it may often be appropriate to formalize communications that are specific to the individual project teams, products, and processes.
- End-user level—not only can transaction specifications be standardized across industrial, corporate, or project domains, but they can be developed to support a single type of recurring transaction that takes place between any two parties.

Transaction specification standards could be applied at all four of the above levels simultaneously, leading to the significant management challenge of collecting, organizing, and accessing these specifications. The research reported in this paper addresses this challenge by proposing a tool to support the management of collections of transaction specifications. The proposed tool takes the form of a web-based portal where transaction specifications from all four levels can be collected, organized, and accessed by all of the parties involved in developing, using, and managing the specifications (illustrated in Figure 8-1).

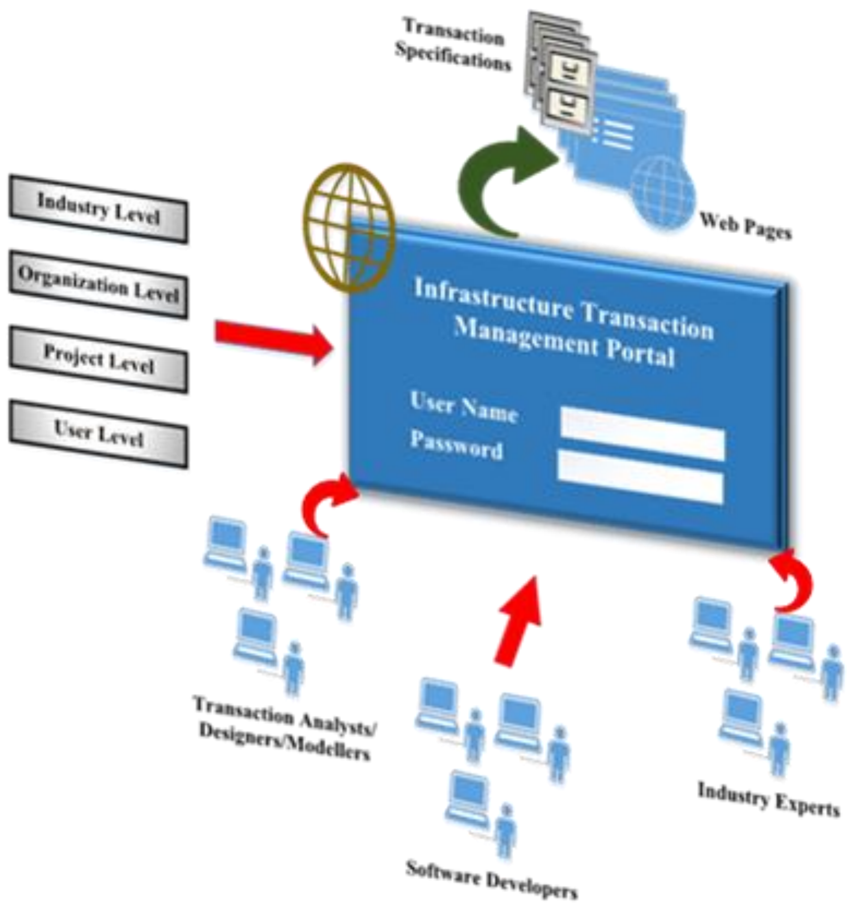

Figure 8-1 Proposed approach

By providing a system that helps information specialists to work with transaction specifications, the research was also intended to help demonstrate and validate the utility of the earlier work on transaction specification ontologies, protocols, and development tools.

8.4 Methodology to Develop the Proposed Portal

The following four-step approach was devised to develop the prototype ITMP using the Microsoft Sharpoint.

Step 1: Create virtual directory—a virtual directory for the prototype ITMP was created on an Internal Information Server (IIS) and a Universal Resource Locator (URL) was assigned to the virtual directory.

Step 2: Create collection site—a collection site was created in the IIS that includes all the sub-sites and web pages.

Step 3: Create sub-sites—sub-sites were created in line with the class hierarchy defined in the Trans_Dom_Onto.

Step 4: Create web pages—three web pages were created to store the following; (i) transaction specification—filled forms; (ii) transaction specification—To-be TM; and (iii) transaction specification—MTs defined for the To-be TM.

8.5 Infrastructure Transaction Management Portal Development

The prototype ITMP was developed using the 4C approach discussed previously. The ITMP development followed the architecture presented in Figure 8-2.

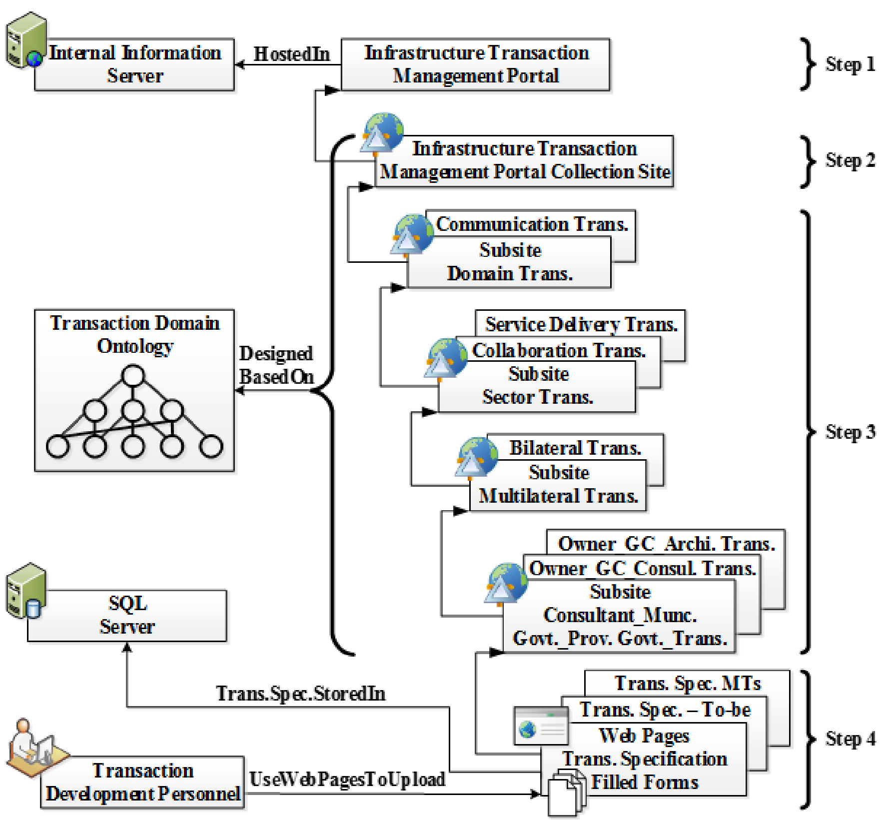

Figure 8-2 Infrastructure transaction management portal architecture

8.5.1 Step 1—Create Virtual Directory

As part of the prototype portal development, a virtual directory for the ITMP was created in the IIS with the name "TransactionManagement", as shown in Figure 8-3. The proposed portal was hosted at this location so that it can be accessed through the Sharepoint Central Administration using the assigned username and password. All the content including the collection site, sub-sites, web pages, and information content are stored at this location.

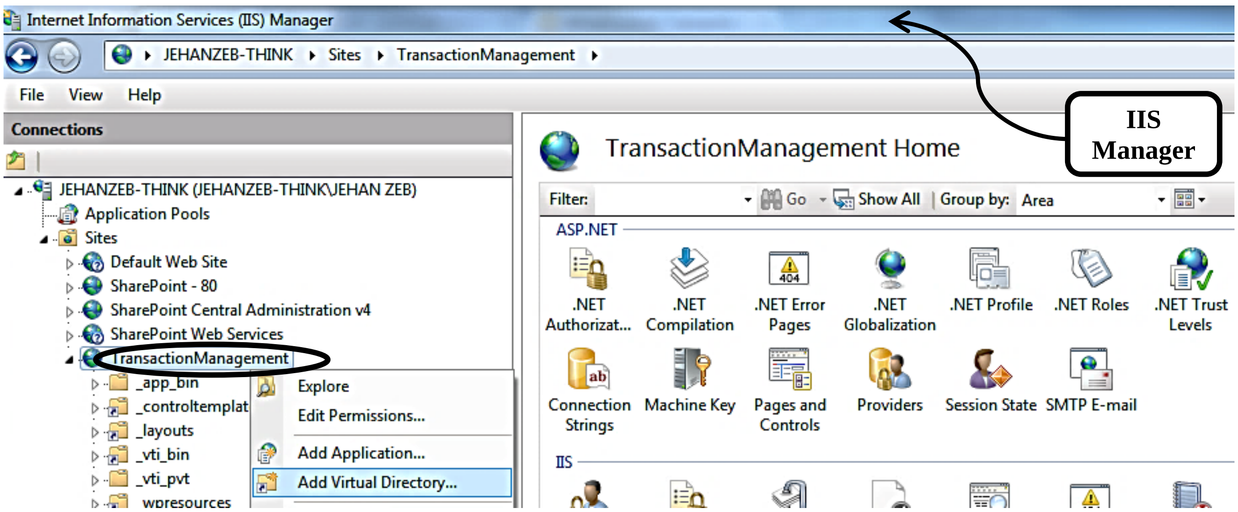

Figure 8-3 Create a virtual directory of the prototype portal

8.5.2 Step 2—Create Collection Site

A collection site, named the Infrastructure Transaction Management Portal, was created to store the transaction specifications according to the transaction class hierarchy represented in the Trans_Dom_Onto. The collection site welcome page is shown in Figure 8-4.

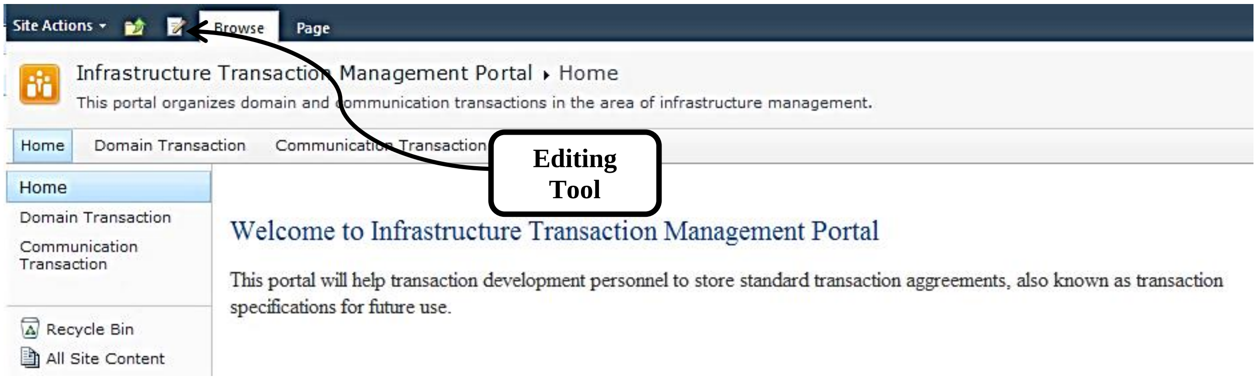

Figure 8-4 Create a collection site of the prototype portal

The purpose of the proposed portal is to help the transaction development personnel to archive transaction specifications according to two main transaction-modalities: domain and communication transaction-modality. The *domain transaction-modality* classifies transactions based on the civil engineering field to which they belong. The *communication transaction-modality* defines transactions based on the way they are communicated between sender and receiver. The content of the collection web site can be changed using the editing tool identified in Figure 8-4.

8.5.3 Step 3—Create Sub-sites

A set of sub-sites was created in the prototype ITMP for each main category of transaction represented in the Trans_Dom_Onto as shown in Figure 8-5. The domain transaction sub-site displays three sub-classes of the domain transaction as shown in Figure 8-5 (a). These sub-classes are: sector transaction, collaboration transaction, and project service delivery transaction. A sub-site for collaboration transactions can be seen in Figure 8-5 (b); it displays two types of transactions: bilateral and multilateral transactions. A sub-site for multilateral transactions can be seen in Figure 8-5 (c), displaying six different types of transactions: (i) Consultant_MunicipalGovt_ProvincialGovt _Transaction; (ii) Owner_GC_Consultant_Transaction; (iii) Owner_GC_Architect_Transaction; (iv) Owner_GC_ Financier_Transaction; (v) Owner_GC_Financier_Transaction; (vi) Owner_GC_Consultant_Architect_Transaction; and (vii) Owner_GC_ Consultant_Agency_Transaction.

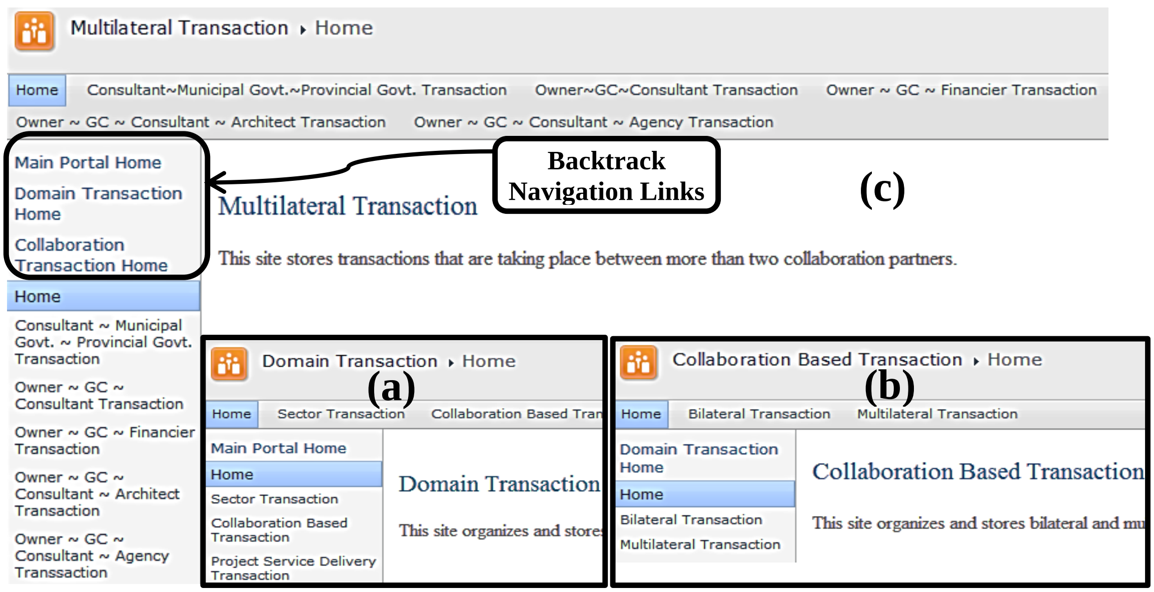

Figure 8-5 Create subsites of the prototype portal; (a) Subsite for the domain transaction; (b) Subsite for collaboration transaction; and (c) Subsite for multilateral transaction

All of these different types of transactions are explicitly defined in the Trans_Dom_Onto, and a brief definition of each type is presented on the respective sub-sites interface. In each sub-site, backtrack navigation links were established to navigate between different sub-sites.

8.5.4 Step 4—Create Web Pages

Web pages were created to archive transaction specifications, which are a combination of three elements: a set of forms filled as part of the process of transaction formalization (i.e. Excel-based forms), the To-be TM (i.e. interaction or sequence diagram) and MTs (i.e. message templates created in InfoPath) defined for each atomic transaction. The portal implements three web pages within each sub-site as shown Figure 8-6. The web page for the transaction specification forms stores the specification while the transaction specification—To-be TM, and the transaction specification—MTs web pages store separately the To-be TMs and defined MTs respectively.

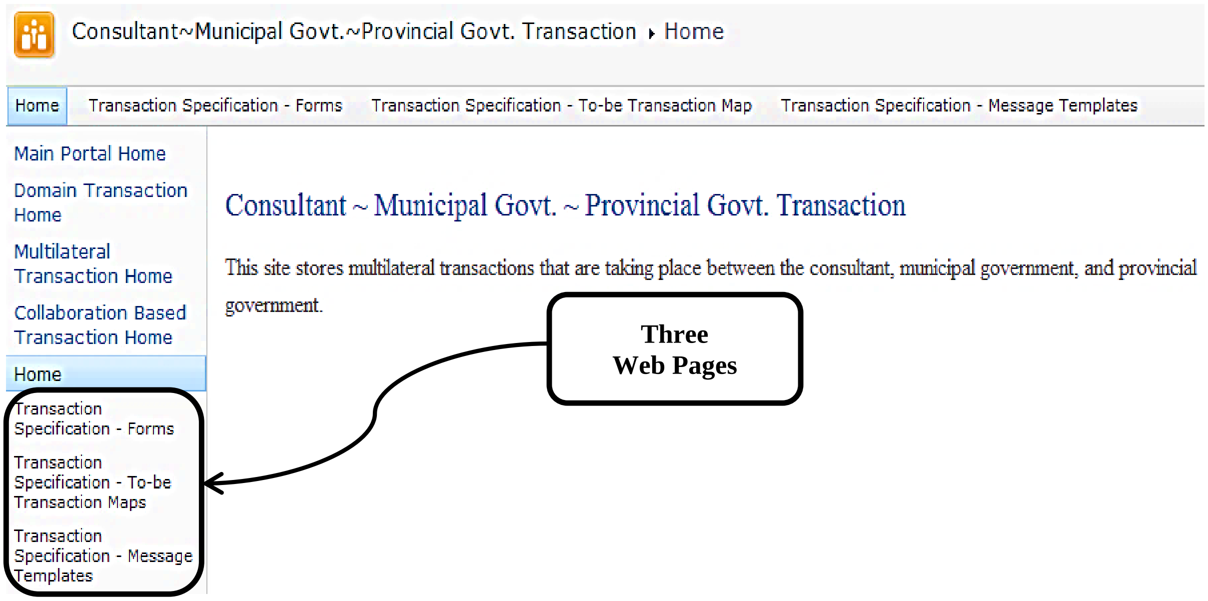

Figure 8-6 Create web pages in subsites of the prototype portal

8.5.4.1 Transaction Specification–Forms Web Page

In the transaction specification—forms web page, a transaction specification document is uploaded to the web page using the "add document" functionality as shown in Figure 8-7. Multiple versions of the document can be added, along with comments identifying each version.

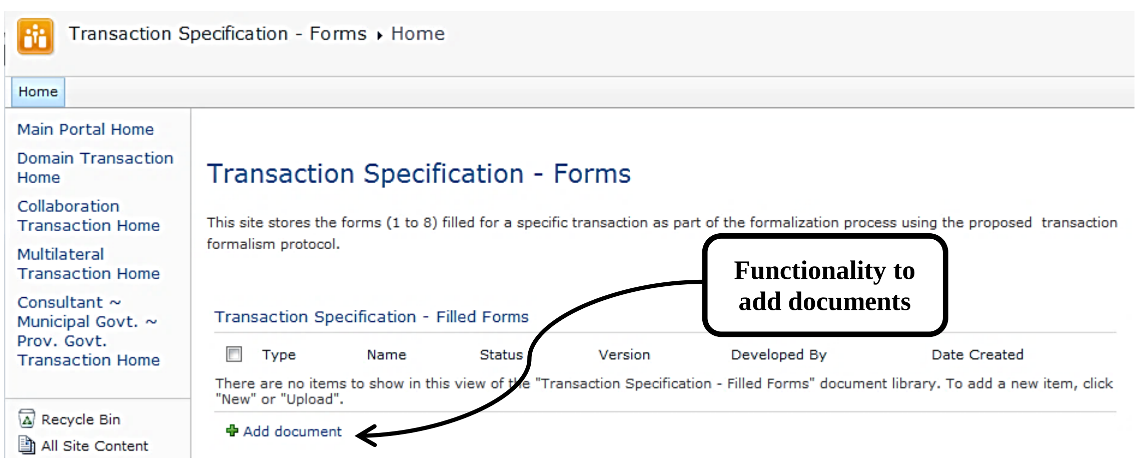

Figure 8-7 Create web pages for transaction specification—forms

After uploading a transaction specification document, a follow-up window opens, as shown in Figure 8-8 (a), which records the meta-information about the transaction specification document. The meta-information includes: name, title, and status of the transaction specification, in addition to the date and the name of the specification developer. The status of a transaction specification shows whether the specification is in draft, reviewed, or approved state. When the meta-information is recorded and saved, the transaction specification document is saved and uploaded to the web page. For example, a transaction specification document along with meta-information for the TCA reporting transaction is uploaded to the web page as shown in Figure 8-8 (b).

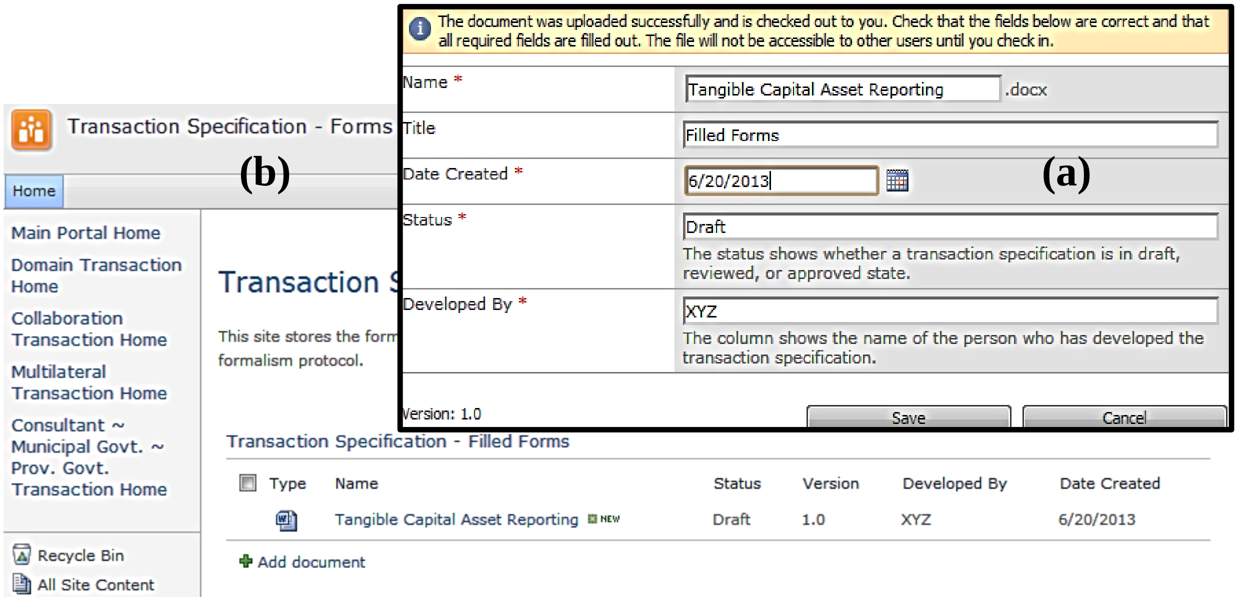

Figure 8-8 (a) Shows the recording of the transaction specification meta information; (b) Shows the attached tangible capital asset reporting transaction specification file

8.5.4.2 Transaction Specification—To-be Transaction Map Web Page

A web page was created to upload and store the To-be TMs. The "add document" functionality is also provided on this web page. The To-be TM file along with the meta-information for the TCA reporting is uploaded as shown in Figure 8-9 (a). Similarly, the To-be TM file can be downloaded by clicking on the name of the "To-be TM, TCA reporting" file as shown in Figure 8-9 (a). Sometimes, the transaction development personnel are also interested in reviewing the To-be TMs of other communication processes that are archived in their respective web pages. In this case, the transaction development personnel need to navigate to the respective location. A navigation hierarchy is shown in Figure 8-9 (b). By clicking on any link in the navigation hierarchy will take the user to that specific location.

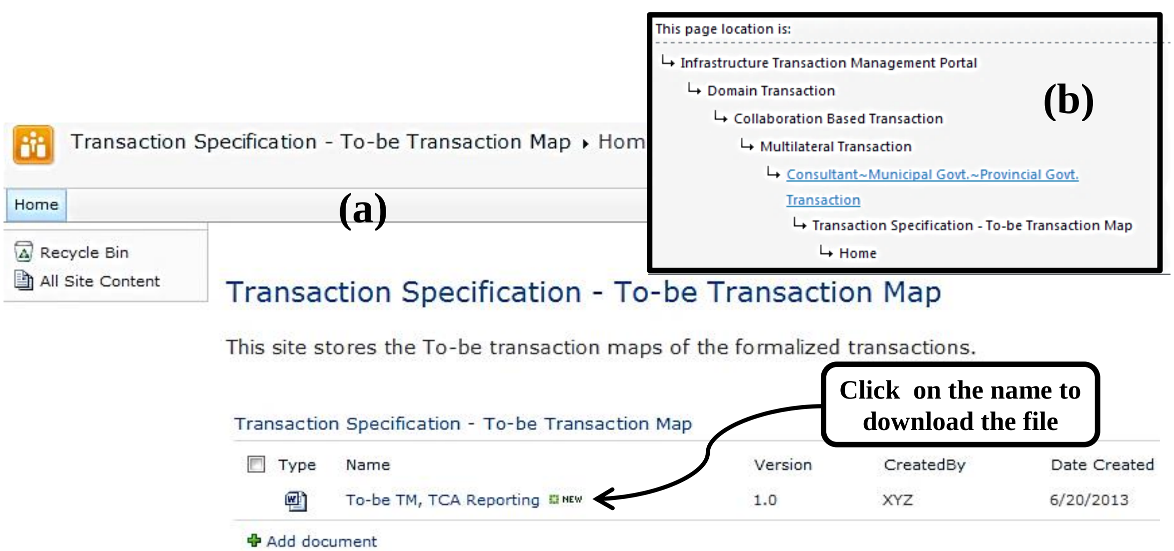

Figure 8-9 (a) Create a web page for transaction specification—to be transaction map; and (b) Portal navigation hierarchy

8.5.4.3 Transaction Specification—Message Template Web Page

A web page was created for the MTs formalized for the To-be TM as part of the transaction specification. A set of MTs defined for different atomic transactions of the TCA reporting are saved to a single document that is uploaded to the web page using the "add document" functionality. The uploaded file can be deleted at any time through "delete" tab from the drop down menu shown in Figure 8-10 (a). An inline editing tool is also available, as shown in Figure 8-10 (a) that enables the transaction development personnel to make changes to meta-information as shown in Figure 8-10 (b). A file can be searched in the portal through the search feature as shown in Figure 8-11. The stored TCA reporting file shown in Figure 8-11 is searched in the portal by name.

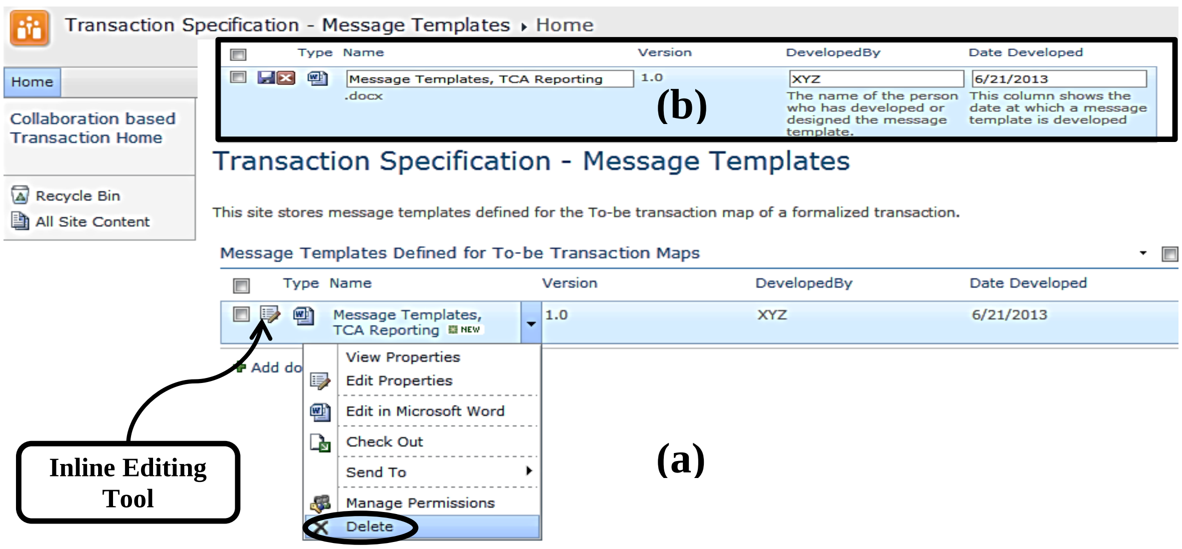

Figure 8-10 (a) Create a web page for transaction specification—message templates; and (b) Inline editing of attached file metadata

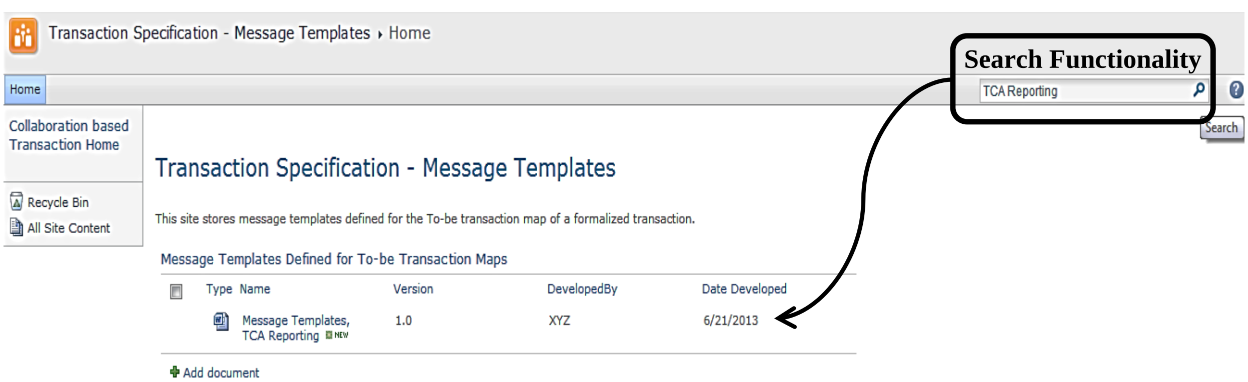

Figure 8-11 The web page shows the search functionality

8.6 Infrastructure Transaction Management Portal Application

The proposed ITMP supports the transaction development personnel to archive and retrieve transaction specifications for implementation into various types of information systems. To demonstrate this process and the utility of the proposed ITMP, this research implemented a scenario where a specific transaction specification, the AI&CAR/TCA

Reporting, was first developed using the TFP Tool as described previously in Chapter 7, which was then stored (archived) in the ITMP. This transaction specification was then implemented in a prototype Asset Information Information System (AIIS), as explained in Chapter 9, that end-users within the infrastructure industry could use to exchange information about infrastructure assets between organizations.

In the AI&CAR/TCA Reporting scenario, municipalities must report their AI&CAR/TCA information to the provincial government for financial planning and funds allocation in accordance with PSAB-3150 regulations. The AI&CAR/TCA Reporting requirement was identified during an IT survey (Zeb *et al.* 2012) and selected as a potential case study in this research work for three reasons. (i) *Manual*—the As-is reporting is manual as the TCA information is exchanged as a report file created in Word doc or PDF formats and sent as an email attachment. In these reports, human interpretation is required at the receiving end, which makes the whole process time-consuming and prone to errors. (ii) *Heterogeneity*—the provincial government receives the TCA information in different formats because different municipalities (cities, districts, towns, and villages) use different information systems to manage their infrastructure systems. (iii) *Non-compliance with regulatory requirements*—the As-is reporting process doesn't comply with the PSAB-3150 reporting requirements for the asset inventory (PSAB, 2008) or SORP reporting requirements of condition assessment (SORP, 2008). The proposed scenario improves upon the current situation by developing a formal transaction specification for the AI&CAR/TCA Reporting, placing this transaction specification into the ITMP, and implementing this specification into an AIIS that municipalities can use to submit their infrastructure asset information in a standardized way and the provincial government can use to receive and aggregate this municipal information.

In the first step of the implementation scenario, the transaction specification for the AI&CAR/TCA Reporting was developed using the TFP Tool, as described previously in Chapter 7. This transaction specification was then stored into the proposed ITMP, as outlined in Section 8.5 of this chapter and illustrated in the top-left portion of Figure 8-12.

In the second step of the implementation scenario, the prototype AIIS was developed that the receiving organization (here, the provincial government) could use to receive municipal tangible capital asset reports in a standardized format, collect the reports, aggregate the results, produce analysis and reports from the aggregate data set. The AIIS is described in detail in Chapter 9 and illustrated in the bottom-right portion of Figure 8-12, which was also implemented using the SharePoint platform. In creating the AIIS, the system developer (who in this case is the author of this research), made use of the AI&CAR/TCA Reporting transaction specification stored in the ITMP as a key reference to provide information requirements for system development. While much of the information requirements contained in the transaction specification are consumed manually by the system developer, some of the elements (the message template) were in a computer-interoperable format that could be read directly by the AIIS system to implement portions of the AIIS.

In the third step of the implementation scenario, municipalities must implement an information system for creating their tangible capital asset reports according to the transaction specification requirements. They have several alternatives for doing this: they can use the AIIS system to produce their reports; they can download the MT from the ITMP and use a simple form-filling application (Microsoft Infopath Filler) to create the reports, or they can implement a customized solution that automatically extracts the necessary data from their local infrastructure management systems and assemble it according to the requirements of the transaction specification contained in the ITMP, which is not yet implemented. Regardless of each municipality's solution, they can produce their reports and submit them to the provincial government's AIIS system in accordance with the transaction specification, as illustrated in Figure 8-12.

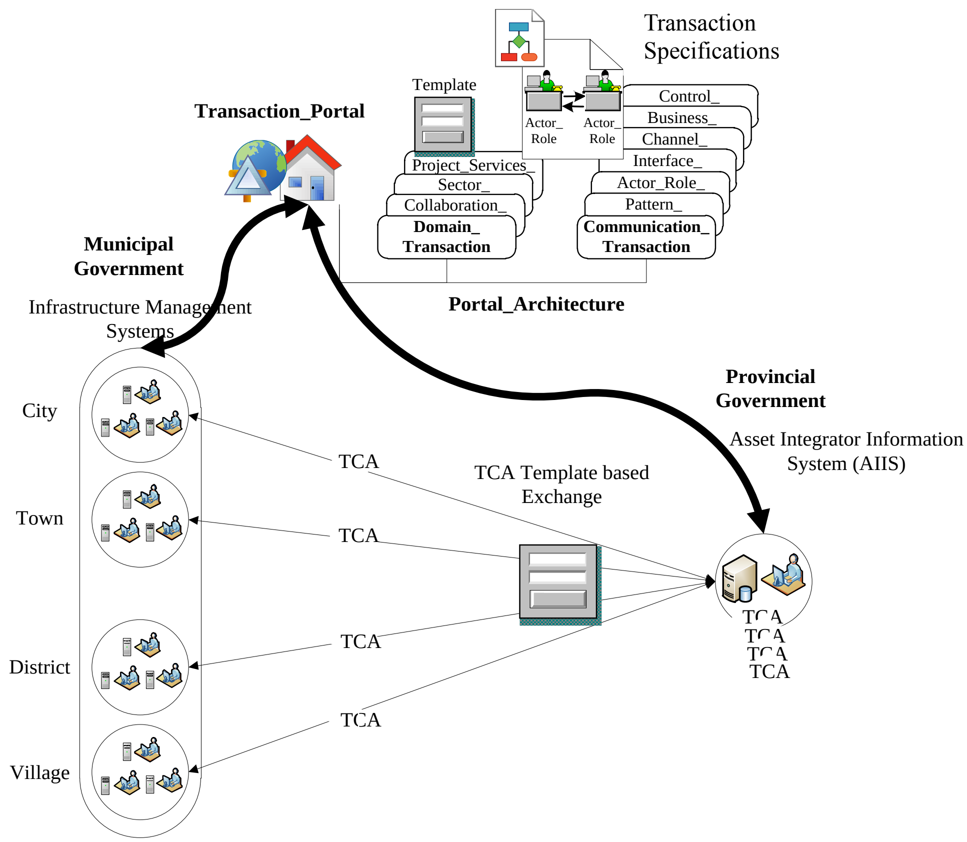

Figure 8-12 Infrastructure transaction management portal application

8.7 Implications and Challenges

A brief identification of the practical implications and challenges of the proposed ITMP is as follows.

Implications—the ITMP enables the transaction development personnel to archive and manage libraries of transaction specifications in a web-based repository. The proposed portal enables the transaction management personnel to search for and retrieve transaction specifications as needed. These transaction specifications can then be used in both human and machine-readable ways to implement standardized computer-to-computer information exchange systems.

The primary purpose of the prototype ITMP within this research is to demonstrate the use of formal transaction specifications and, by doing so, to contribute to the validation of the ontologies (i.e. transaction domain ontology and tangible capital asset ontology) and the TFP developed as part of this research work. The ITMP is not, itself, a primary contribution of this thesis and thus end user testing and validation is not called for.

Limitations/challenges—the proposed portal is a prototype only showing a limited number of sub-sites, web pages, and functionalities. The portal can easily be extended when more specifications are developed in the future. Due to the current focus of this research work, only corporate-wide transaction specification have been developed; industry-wide, project-wide, and user-wide transaction specifications are yet to be developed. Finally, the portal was developed in the SharePoint platform, the installation of which was a time-consuming and cumbersome process, which required specific IT expertise and skills.

8.8 Conclusions

Municipal organizations must exchange accurate data in order to provide efficient management of the infrastructure systems. This data exchange is currently performed manually and on an *ad hoc* basis. The growing trend in the infrastructure community is to transform these manual communications to a more formalized computer-to-computer based exchange of information. In this research work, these transactions are formalized as transaction specifications. One of the research questions was, “how to manage transaction specifications?” The management of specifications is identified as an important issue in the industry as all of the state-of-the-art, work process and communication formalization standards and methodologies focused on the development of the specifications, and not on its management. This gap in the current research provides an opportunity that can be explored for the domain with respect to management of transaction specifications. To respond to the question, an ontology-supported ITMP was developed.

The ITMP was developed through a four-step (i.e. 4C) procedure using the SharePoint platform. First, a virtual directory was created in the IIS. Second, a collection site (i.e. ITMP) was created. Third, a set of sub-sites were created. Fourth, three web pages were created in each sub-site to store the three elements of a transaction specification: transaction formalization documentation, To-be transaction map, and a set of message templates.

The prototype ITMP was designed according to a layered architecture where each layer represents a specific step. The portal architecture was organized according to the 4C approach devised for this research work. Following this layered architecture, the proposed portal was developed using the transaction domain knowledge represented in the Trans_Dom_Onto built as part of this research work. The sub-sites in the prototype portal were created according to the two main abstract transaction-modalities: domain and communication transaction-modality. Each sub-site represent a specific class of a transaction defined in the domain and communication transaction-modalities. Three web pages were created in each sub-site to manage (archive) the three elements of the transaction specification separately.

An application of the proposed ITMP was presented to demonstrate how the transaction development personnel and industry experts will use the portal. As an example, the AI&CAR/TCA Reporting transaction was used both in the portal development and application. In the future, the prototype portal will need to be transformed to a full fledge portal representing a complete set of transaction classes (sub-sites), web pages, and functionalities to accommodate the growing number of transaction specifications in future.

Chapter 9 Asset Information Integrator System

9.1 Introduction

A transaction specification—Objective 4 (a) (the case study), for the Asset Inventory and Condition Assessment Reporting/Tangible Capital Asset (AI&CAR/TCA) Reporting was developed using the proposed ontology-supported Transaction Formalism Protocol (TFP) that is discussed in detail in Chapter 4, 5, 6, and 7. The AI&CAR/TCA Reporting is a communication process in which various municipalities report their Tangible Capital Asset (TCA) information to the provincial government. The formalized transaction specification for the AI&CAR/TCA Reporting was managed through developing an Infrastructure Transaction Management Portal (ITMP)—Objective 4 (b), as explained in Chapter 8. The transaction specification was then implemented in the Asset Information Integrator System (AIIS)—Objective 4 (c), as described in this chapter, to demonstrate the proposed approach.

This chapter[9] consists of six sections that describe the development and application of the AIIS. The proposed AIIS was developed using a four step procedure. The chapter further discusses the application of the AIIS, which means how the system works to exchange the TCA information between various municipalities and the provincial government. The application of the AIIS was divided into four components: users, actions, message templates defined for the exchange of the AI&CAR/TCA information, and software.

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[9] A version of this chapter has been submitted for publication to the Candian Society for Civil Engineering Annual Conference and Built Environment and Asset Management Journal.

Zeb, J. Froese, T. and Vanier, D. (2014). "Knowledge-Enabled Tangible Capital Asset Reporting Using Asset Information Integrator System in Infrastructure Management", General Conference, Candian Society for Civil Engineering, May 28~31, 2014, Halifax, NS, pp. GEN-17-1~10. The main focus of this paper was to briefly introduce the development and application of the Asset Information Integrator System.

Zeb, J. Froese, T. and Vanier, D. (2014). "An Ontology-Supported Asset Information Integrator System in Infrastructure Management", Accepted for Publication, Built Environment Project and Asset Management, Emerald Publishing Inc. This paper introduces the two ontologies at the abstract level: Transaction Domain Kernel Ontology and Tangible Capital Asset Ontology, and explains the detailed development and application of the Asset Information Integrator System.

9.2 Literature Review

This research work builds on two primary knowledge domains: ontology development and information systems in the area of infrastructure management. The primary references that led to the development of the proposed AIIS include: Infrastructure Product Ontology, IPD-Onto (Osman, 2007), Infrastructure and Construction Process Ontology, IC-Pro-Onto (El-Gohary, 2008), Actor Ontology, Actor-Onto (Zhang and El-Diraby, 2009), Transaction Domain Ontology (Zeb and Froese, 2012), and Tangible Capital Asset Ontology, TCA_Onto (Zeb and Froese, 2013). A detail analysis is given in Chapter 1, Section 1.4.3.

Similarly, information systems were studied for carrying out a variety of work processes in the domain of infrastructure management, including: asset inventory management, asset condition assessment, asset service life analysis, asset life cycle cost analysis, asset risk analysis, and decision making analysis (Vanier and Rahman, 2004). The applications that are currently in use for carrying out above-mentioned work processes includes: dTIMs, Hansen, ArcGIS, Road Matrix, Web Works, RIVA, SAP, MS Excel, City Works, AMS, Mapguide, A2B, Microstation, VFA, AutoCAD, and MapInfo (Zeb *et al.* 2012). Detailed analysis of these systems is given in Chapter 2, Section 2.4.

9.3 Development Methodology

The proposed AIIS is a web-based prototype system developed using the SharePoint platform. According to Microsoft (2012), *SharePoint* is a platform that is used to create *websites*, helps *communities* of people to collaborate, provides a place to put information *content*, allows *searches* of the content stored on the Sharepoint server, helps in bringing all the information together to provide better *insights*, and allows extension and customization without having extensive programming skills and knowledge *composite*. The SharePoint platform was adopted due to its robustness and ease of use. The following methodology was devised to develop the proposed web-based AIIS in line with the approach presented in Microsoft (2012) and Parren *et al.* (2010).

Step 1: Create website and library—a website for the AIIS was developed first using a 4C approach: create a virtual directory in the SharePoint Internal Information Server (IIS); create a collection website to host all subsites; create subsites to host all web pages; and create web pages to represent the information and functions that the experts will use to archive the TCA reports. Once the AIIS was developed, a form library based on theAI&CAR/TCA Message Template was created to store all the TCA reports received from various municipalities.

Step 2: Review and modify message templates—it was assumed that the MTs to be implemented in the proposed AIIS system had previously been developed based on the knowledge represented in the two ontologies (Trans_Dom_Onto and TCA_Onto) as part of the transaction specification development. An additional step—create the MTs—would be needed in cases where the MTs were not previously developed. The formalized MTs were reviewed to check that different functionalities and validation rules associated with MT fields were working properly. The required site-specific changes were incorporated before implementing the formalized MTs into the AIIS.

Step 3: Design and configure workflow—the workflow was designed according to the To-be transaction map (To-be TM) defined as part of the transaction specification developed for the AI&CAR/TCA Reporting. The workflow was designed using a combination of MS VISIO and SharePoint Designer. In VISIO, the workflow was defined as a

SharePoint workflow, which was then exported to SharePoint Designer for further process configuration. During the configuration, a set of actions and conditions were applied to the workflow. The workflow could be designed and configured using the SharePoint Designer only, but it was found that VISIO makes the workflows easy to create, visualize, modify, and integrate with other applications like SharePoint Server and SharePoint Designer.

Step 4: Add functionalities—a set of functionalities was defined in the AIIS. These functions were: add reports, edit reports, delete reports, download reports, search reports, navigate through the AIIS system, integrate reports, compare reports, and visualize workflows and reports.

9.4 Asset Information Integrator System Development

The proposed AIIS was developed using the aforementioned four-step approach.

9.4.1 Step 1—Create Website and Library

A 4C approach was used to develop the web-based AIIS system. *Create a virtual directory*—a virtual directory was created on the Internal Information Server of the SharePoint. All information, transaction instances, and documents being exchanged through the AIIS are stored at this location. *Create collection website*—a collection website was created in the virtual directory to store all subsites and web pages as shown in Figure 9-1 (a). *Create websites*—a set of websites in the form of libraries, lists, and discussions was created. To store the TCA reports received from various municipalities, a library with the name AI&CAR/TCA Reporting was created as shown in Figure 9-1 (a).

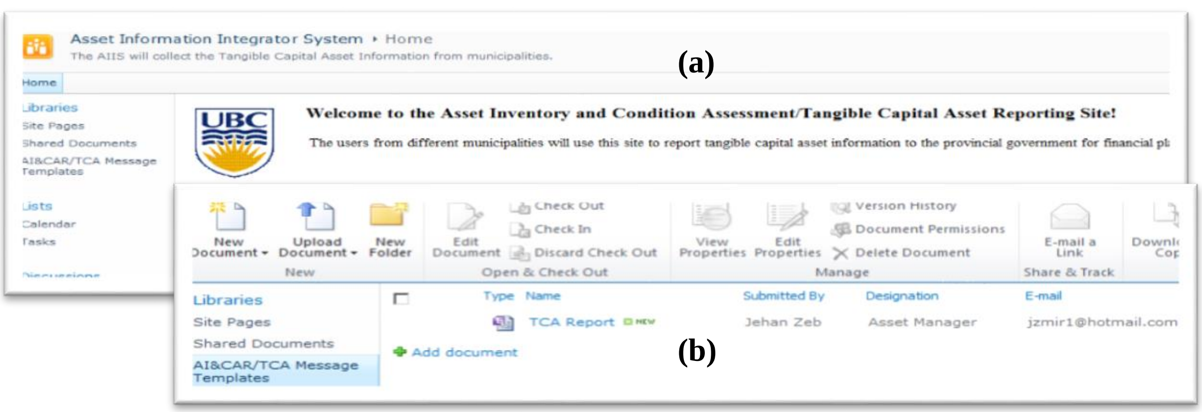


Figure 9-1 (a) Create asset information integrator system website and a library and; (b) Library attributes

Depending upon the requirements of the users, some attributes (e.g. name of the TCA report, submitted by, name of the municipality, type of municipality, date submitted, etc.) were also defined for this library. These attributes were the various fields represented in the MT defined for the AI&CAR/TCA Reporting. A separate column was added in the library to represent each attribute. Once a TCA report is submitted, it is stored with the these attributes as shown in Figure 9-1 (b). The benefits of adding/defining fields (attributes as column headings) from the MTs to the library are: searching—the documents or MTs added to the library can be searched using column headings; sorting—the users can sort different MTs added to the library based on column heading; filtering—similarly the added MTs can be filtered using column heading; and creating different views. *Create web pages*-to introduce the AIIS to the user, a welcome web page was created as shown in Figure 9-1 (a).

9.4.2 Step 2—Review and Modify Message Templates

It is assumed that the MTs for each atomic transaction of the AI&CAR/TCA Reporting was already designed using the Microsoft InfoPath Designer as part of the transaction specification development. In case the MTs were not defined, then an additional step of "create MTs" would be required before the "review and modify MTs" step. The MTs were opened and reviewed in the Microsoft InfoPath Designer to check that various functionalities (e.g. sum, product, formula, etc.) associated with each field was working properly before implementing it in the AIIS. While defining the MT for the AI&CAR/TCA Reporting, some validation rules were applied to each field in the message header and payload section as shown in Figure 9-2 (a) and (b) respectively. Validation rules were used to check that the format of information was correct and the functionality associated with a specific field was working properly. The message header section contains information that was captured from the Trans_Dom_Onto. The information shown in the message payload section was captured from the TCA_Onto representing view 1 of the multi-view MT defined for the AI&CAR/TCA Reporting. This MT has eight views with each view representing the TCA information within a specific infrastructure sector. The users can switch between different views by clicking on the required view.

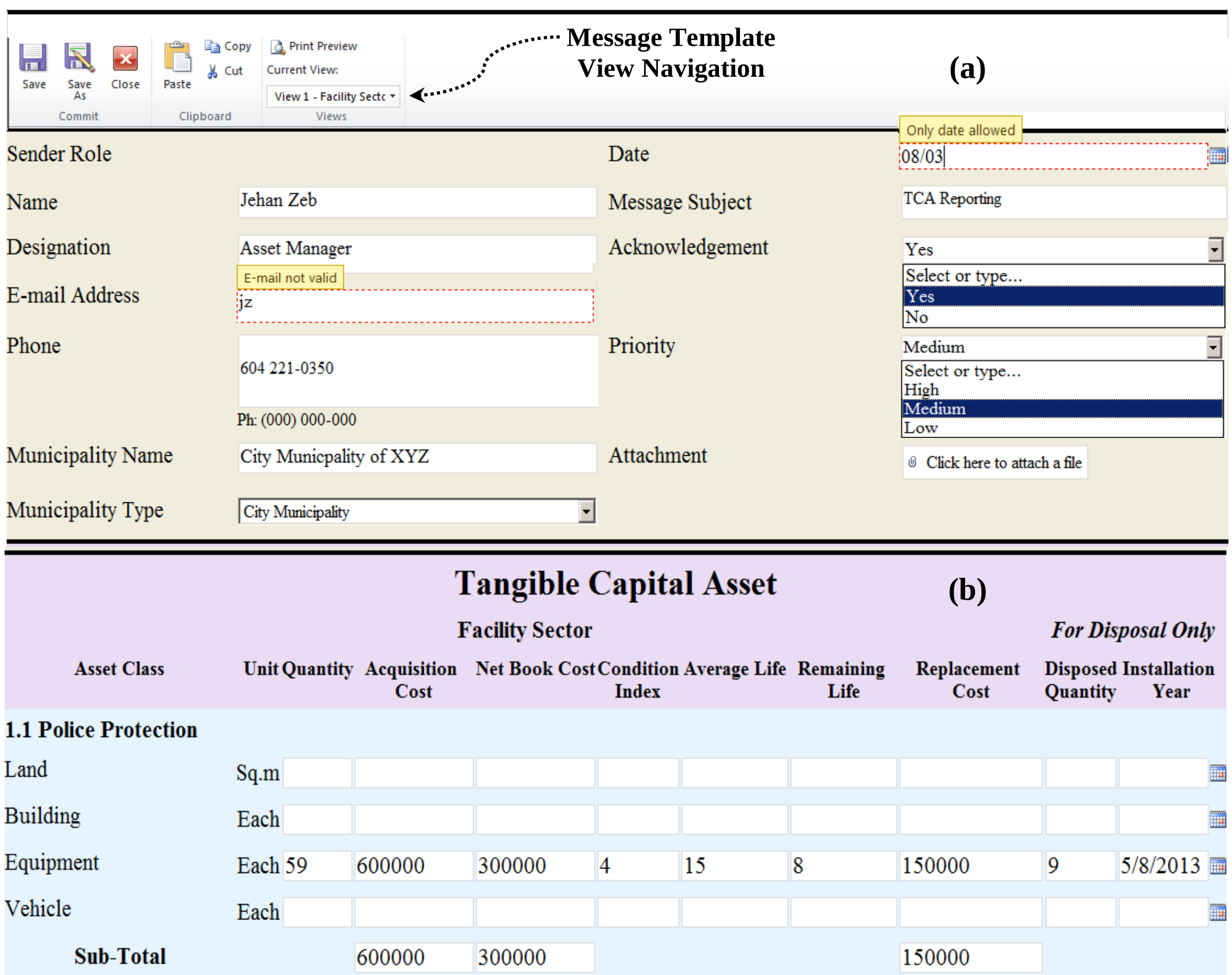


Figure 9-2 Review and modify message template; (a) Message header section (show examples of validation rules); and (b) Message payload section

9.4.3 Step 3—Design and Configure Workflows

The workflows are repeatable automated business processes that are designed based on the To-be transaction map created as part of the transaction specification development. The workflow is an implemented version of the TM. For instance, the TM developed for the AI&CAR/TCA Reporting was implemented as a SharePoint workflow. The TM developed for the AI&CAR/TCA Reporting is presented in Figure 9-3. The TM shows a holistic view of the communication that must take place between different infrastructure organizations for the exchange of AI&CAR/TCA information. In this research work, only the communication between different municipalities and the provincial government was implemented as a SharePoint workflow to demonstrate the prototype AIIS. This is a relatively simple communication that, in current practice, is often implemented using email attachments. Yet, there are advantages to implementing a transaction, such as this, using a workflow server approach, including: *activity tracking*—keeping track of all activities using a history of all tasks and events; *status tracking*—activity status is tracked to ensure timely completion of tasks and transactions; and *information security*—only users with the required permission are allowed to exchange the TCA information using a highly secure network. In this research, the workflow was first designed in MS VISIO, which was then exported to the SharePoint Designer for further process configuration.

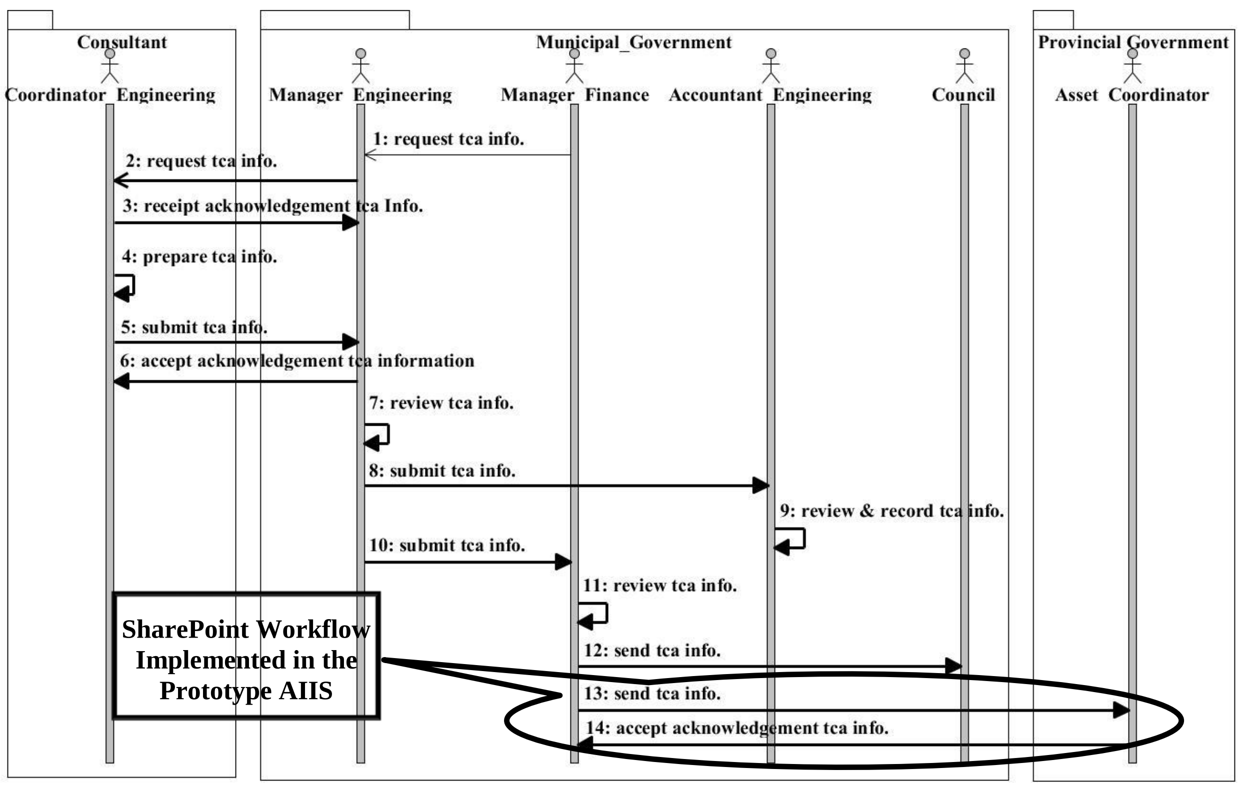


Figure 9-3 Transaction map developed for asset inventory and condition assessment/tangible capital asset reporting

9.4.3.1 Design Workflow

The workflow was designed in MS VISIO as a SharePoint workflow and was named "TCA Reporting" as shown in Figure 9-4. The SharePoint workflow is generally composed of a starter, a terminator and a set of actions (e.g. send, receive, review, approve, etc.) and conditions (e.g. decision statements, such as "if the result is yes, follow route A, otherwise, follow route B"). For the TCA Reporting workflow, as a simple demonstration transaction, included no conditions and three actions: log the TCA information to the history list, review the TCA information, and send an accept acknowledgement message to the sender. The *first action* is to log all the actions to the history list that archives all TCA information exchanged through the AIIS. The *second action* is to send the TCA information to an expert within the provincial government for review, and the *third action* is to send an accept acknowledgment message to the sender of the TCA information. All of these actions were fully automated. The TCA Reporting workflow diagram was checked for rules validation and a validated workflow diagram was then exported as a VISIO Workflow Interchange file (vwi) to the SharePoint Designer for configuration.

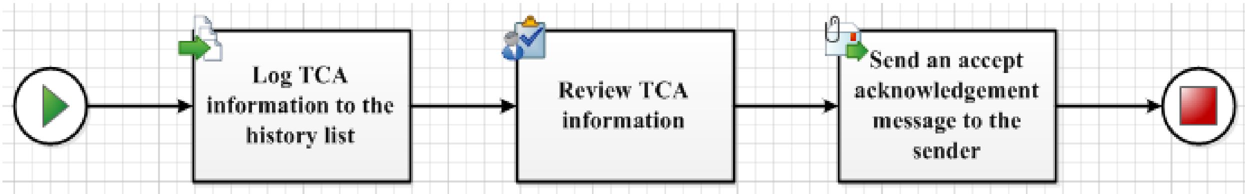


Figure 9-4 Validated SharePoint workflow diagram

9.4.3.2 Configure Workflow

In the SharePoint Designer, the TCA Reporting workflow diagram was imported as vwi file for configuration. The term "configuration" means explicitly defining the workflow rules. When the TCA workflow diagram (vwi file) was imported to the SharePoint Designer, it was transformed into a set of statements (non-configured TCA workflow), as shown in Figure 9-5 (a). Each action defined in the TCA Reporting workflow diagram was converted into two statements. The top statement written in gray represents the action As-is, whereas the lower (bolded) statement is an automated generated statement that needs to be configured. Each of the underlined words were configured by applying rules. The term "ID3" was changed to represent the name of the workflow—TCA Reporting and all action statements were defined as shown in Figure 9-5 (b). The statement "this message" was explicitly defined as "TCA information". The action statement "a to-do item" was assigned to the "Review TCA information" action, and the "these users" role was directed to a specific user to whom the TCA report was to be directed. The final "these users" role in the last line represents the sender of the TCA information to whom an accept acknowledgement message was to be sent. During the configuration, the review action message and accept acknowledgement message was automatically generated that was used during the TCA Reporting.

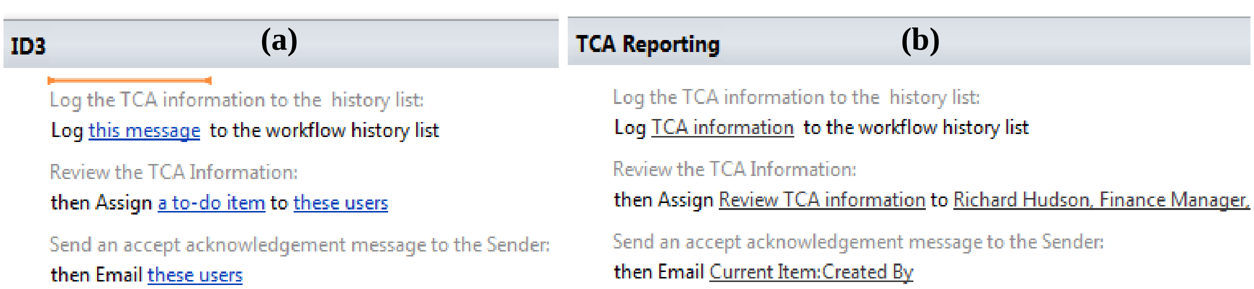


Figure 9-5 (a) Non-configured workflow; and (b) Configured workflow

Next, the TCA workflow settings were configured before associating it with the AI&CAR/TCA MTs library. The "workflow visualization on status pages" was checked to enable diagrammatic representation of the workflow status at any point in time. In the TCA workflow "start options" settings, automatic start up was checked, which means the TCA workflow will automatically start when a TCA report is created or changed. When the TCA Reporting workflow setting was completed, it was associated with the library AI&CAR/TCA MTs.

9.4.4 Step 4—Define/Add Functionalities

Some functionalities (e.g. sum, average, formula, etc.) were defined in the prototype AIIS as shown in Figure 9-6 (a) and (b). These functionalities were used to develop visual representations of the TCA reports as part of the visual analytics. For instance, the provincial government wants to see visual representations of the cumulative acquisition, net book value, and replacement costs based on the municipality type (city, town, district, and village). These visual representations lead to effective and efficient decision making. The screen captures shown in Figure 9-6 (a) and (b) shows how the sum and average functionalities were added to create fully automated real-time visual representations of the TCA reports. These functionalities were added using an add-in application, "Collabion Charts for SharePoint" (Collabion, 2014), which is a third party application that is developed for creating charts in the SharePoint. Other functionalities (e.g. collect reports, edit reports, delete reports, download reports, search reports, navigate through system, integrate reports, compare reports, and visualize workflows and reports), were also defined.

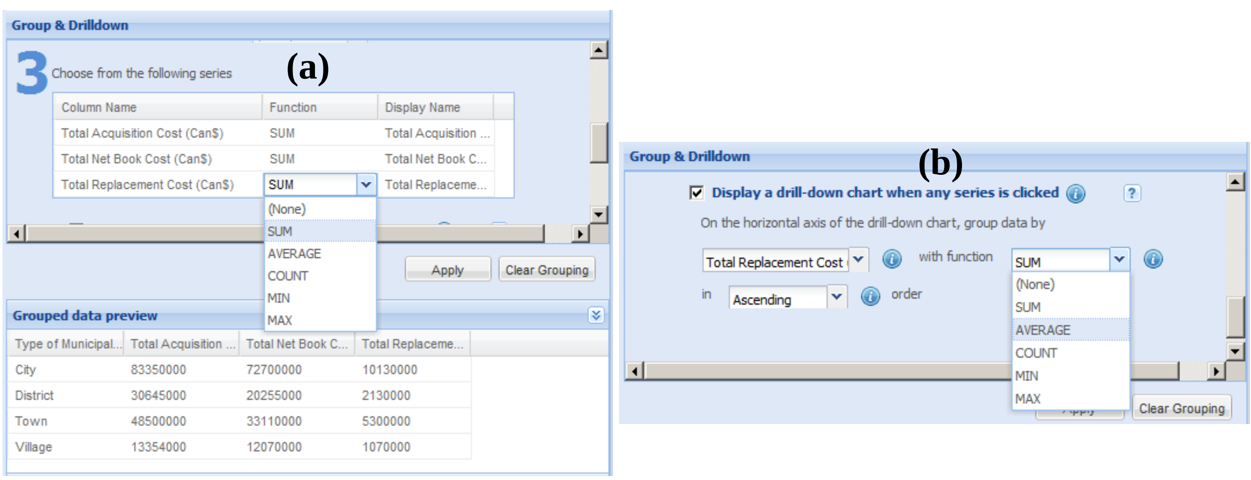


Figure 9-6 (a) Adding sum function; and (b) Adding average function

9.5 Asset Information Integrator System Application

The proposed AIIS was developed for the reporting of the AI&CAR/TCA information between the municipal and provincial government. Presently, the municipal organizations exchange this information in a manual and *ad hoc* way in the form of a PDF or Word file due to heterogeneous and inconsistent data formats. To transform to a more computer-based exchange of the TCA information, the AIIS implemented standardized MTs that were defined based on the knowledge represented in the two ontologies developed as part of this research work. The AIIS collects the TCA reports received from various municipalities via standardized MTs and integrate them with back-end applications (MS Excel, Excel Services within SharePoint, SharePoint Reporting Services, etc.) for further processing and analysis. The AIIS application demonstrates how the industry experts could use computer-to-computer information exchange.

It gives an overall picture of how different components of the prototype AIIS are interrelated. The AIIS is composed of four main components as shown in Figure 9-7: users, actions, message templates exchanged, and software used.

Users—the municipal and provincial government are the two main users of the AIIS. *Actions*—the most important actions are fill, send, receive, etc., which the municipal and provincial governments use to accomplish the AI&CAR/TCA Reporting. *Message templates*—the MTs defined as part of the AI&CAR/TCA reporting specification development include two message templates: the AI&CAR/TCA Reporting MT and accept acknowledgement MT. The municipal government instantiates the AI&CAR/TCA Reporting MT each time they report their AI&CAR/TCA report to the provincial government. *Software*—a diverse range of software applications are used to accomplish various actions. This component specifies how a specific action can be completed in the AIIS using a specific software, i.e. MS InfoPath Filler, MS Outlook, MS SharePoint, MS Excel/SharePoint Excel Services, and MS Exchange. The following discussion of the AIIS application is organized according to the sequence of actions presented in Figure 9-7.

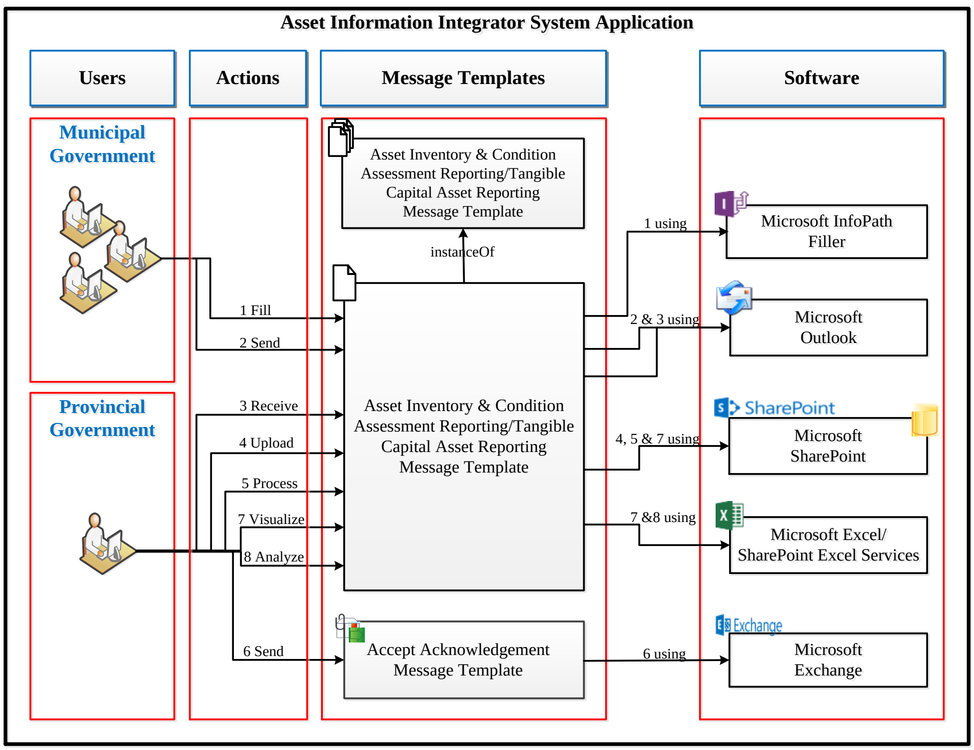


Figure 9-7 Asset information integrator system application

9.5.1 Action 1—Fill the Message Templates

Once the municipal government has compiled all the TCA information required for reporting, the next step is to report it to the provincial government for financial planning and fund allocations. In the scenario illustrated by the AIIS, the municipal government has specified the MT defined for AI&CAR/TCA Reporting and has provided this to municipalities. The municipalities have a range of options for working with this MT, including Microsoft InfoPath Filler or SharePoint Form Services. The choice of applications depends upon the type of the municipality, affordability and availability of the human resources. Small village municipalities may choose to use MS InfoPath Filler, which is a simple, stand-alone application (with low cost and easy availability) used for completing form templates. The MTs include buttons to save, next, back, and submit actions, which makes the form filling process simple for the users. For example, the user can save the data at any time and can come back later to complete the form, navigate between multiple views, and submit the filled form directly through the "submit button" View 1 of the multi-view form developed for the AI&CAR/TCA Reporting was shown previously in Figure 9-2 above.

9.5.2 Action 2—Send the TCA Information

If a MT is filled in using MS InfoPath, it can be sent to the provincial government via E-mail using the submit functionality as shown in Figure 9-8 (a). The email account configuration enables municipalities to send the AI&CAR/TCA MT directly from the their client application (InfoPath filler) to the provincial government as an XML file attachment to an email message. After configuration was completed, the AI&CAR/TCA MT was sent to the provincial government. The successful submission notification is presented in Figure 9-8 (b). This represents a simple and accessible mechanism for submitting the MT, but a wide range of more advanced alternatives are also possible.

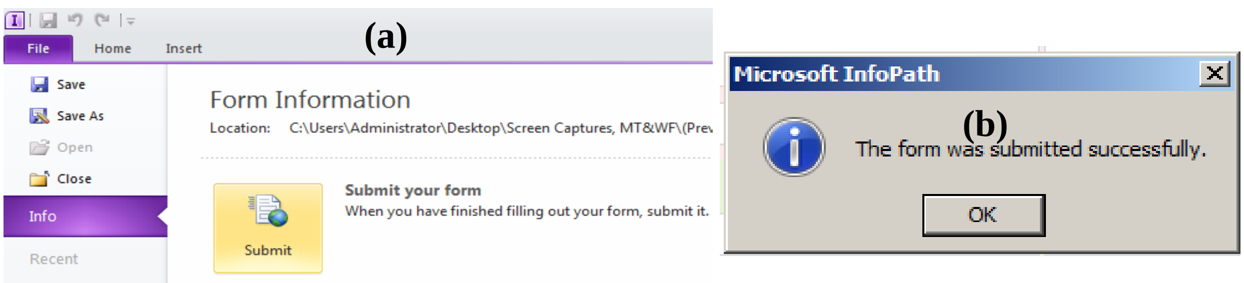


Figure 9-8 (a) Submit option functionality in infopath filler and (b) Successful submission notification

9.5.3 Action 3—Receive the TCA Information

In this example, the provincial government receives the filled AI&CAR/TCA MT (i.e. the TCA Report) as an E-mail file attachment as shown in Figure 9-9 (a). The TCA Report (i.e. filled MT) was received as an XML file attachment as shown in Figure 9-9 (b), which also shows the E-mail body information. The TCA Report was downloaded in XML format for further uploading to the web-based AIIS.

Figure 9-9 (a) Inbox showing receipt of the tangible capital asset report; and (b) TCA report attached as an XML file

9.5.4 Action 4—Upload the TCA Information as List Item

After the provincial government received the AI&CAR/TCA Reports from different municipalities, the next step was to upload and store these reports as a list item in the library (AI&CAR/TCA MTs) previously created in the AIIS. A set of column headings (representing the TCA Report attributes) was defined in the library that were linked to the fields in the MT. Each time a report was uploaded or added to the library, the information in the columns were automatically retrieved from the MT and updated accordingly. The set of columns selected for this library was based on the requirements of the provincial government for instant data analysis. A report was uploaded to the library using the upload document icon in the ribbon as shown in Figure 9-10. When the upload document was selected from the drop-down list, it leads the user to the location where the TCA Report XML file was saved. After selecting the TCA Report XML file, it was uploaded to the library as a list item and the library column information (attributes) were updated automatically as shown in Figure 9-10.

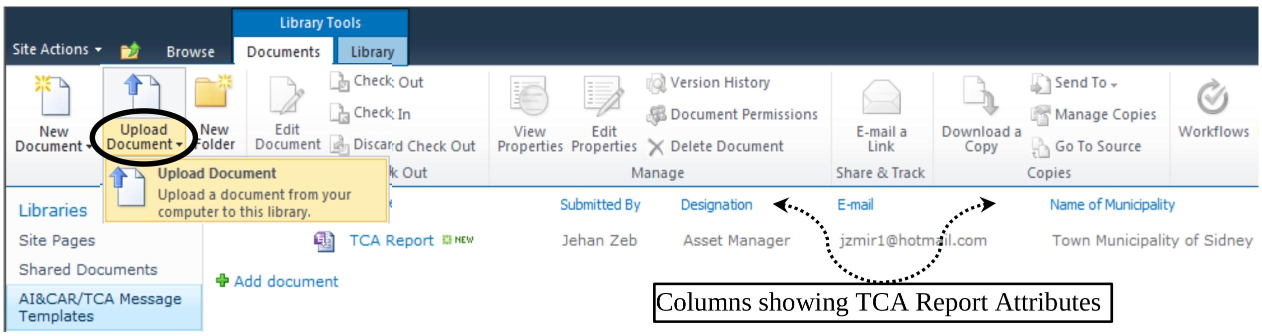


Figure 9-10 Uploaded tangible capital asset report

9.5.5 Action 5—Process the TCA Information

The workflow attached to the AI&CAR/TCA MTs library in the AIIS was kicked off when a TCA Report was uploaded. The TCA report was processed and its' status, in-progress or completed, can be seen in the last column of the Figure 9-11 (a). The TCA report processing can be seen visually at any point in time as shown in Figure 9-11 (b).

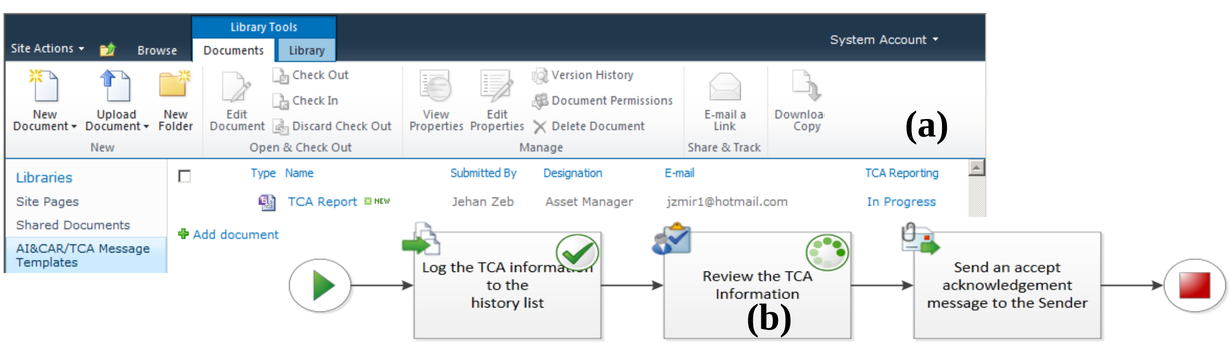


Figure 9-11 (a) Processing of the tangible capital asset report is in progress; and (b) Work flow status visualization

The workflow shows that the first task, "log the TCA information to the history list" is completed, the second task, "review the TCA Information" is in progress, and the third task, "send an acknowledgement message to the sender" is not yet started. A completed task in the visual representation is shown with a "√" mark, an ongoing task is shown as a circle with dots insides, and a task that is not yet started is represented without any symbol.

The next task "review the TCA information" was assigned to an individual responsible for the review of the TCA report at the provincial level. A notification was sent to the reviewer notifying that a review task is pending. The individual responsible for the review, clicked on the task tab as shown in Figure 9-12 and opened the TCA report that was required to be reviewed. When the review task was completed, it was shown as completed under the "outcome" column as shown in Figure 9-12.

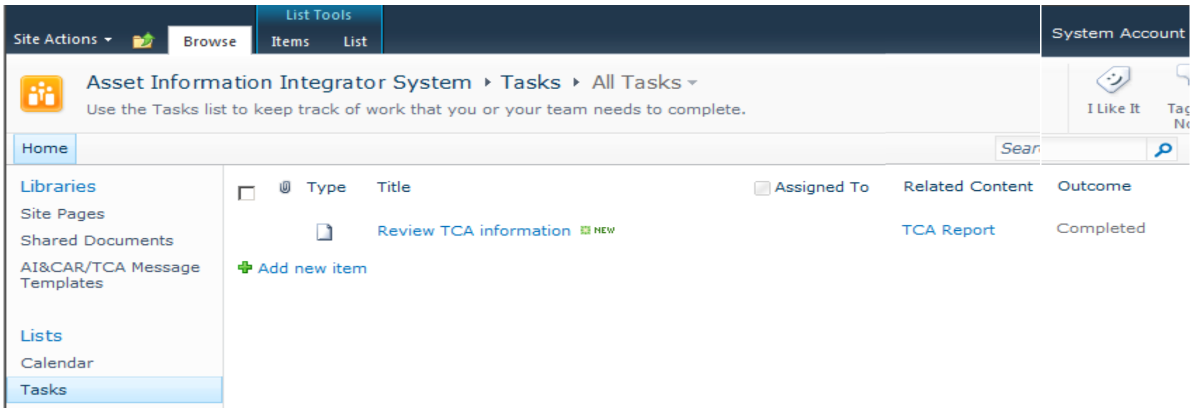


Figure 9-12 Review task is completed

9.5.6 Action 6—Send Accept Acknowledgement Message

After the TCA review task was completed, an accept acknowledgement message was sent to the respective municipality using the MS Exchange. All the three workflow tasks were completed as visualized in the Figure 9-13.

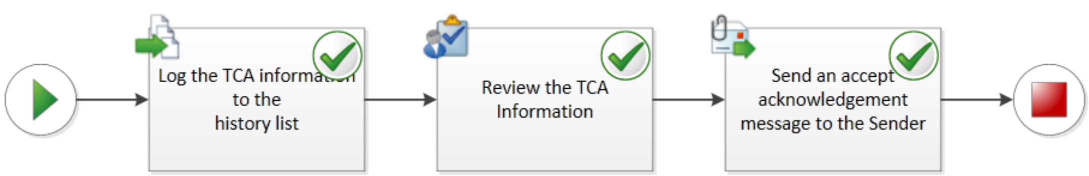


Figure 9-13 Send accept acknowledgement message

9.5.7 Action 7—Visualize the TCA Information

A set of 10 TCA Reports, three each from city, town, district, and village municipalities, were filled with dummy values and were uploaded to the prototype AIIS as shown in Figure 9-14. For each TCA report, the workflow attached to the library was run to complete all the three workflow tasks discussed above. The last column "TCA Reporting" shows that workflow tasks are now completed. The information in all other columns was automatically updated when a TCA report was uploaded to the AIIS. For a quick review of the TCA Reports submitted by different municipalities, the provincial government may want to see graphical representations of the TCA information. For this purpose, the list information was transformed into a real-time graphical representation within the SharePoint environment using the Collabion charts add-on developed for the SharePoint. For the list items (TCA reports) shown in Figure 9-14, two types of graphs were developed as shown in Figure 9-15.

Site Actions | Browse | Library Tools | Documents | Library | System Account

Asset Information Integrator System ▸ AI&CAR/TCA Message Templates ▸ All Documents

This library will stores message templates designed for AI&CAR/TCA reporting transaction.

Type	Name	Name of Municipality	Type of Municipality	Date Submitted	Total Acquisition Cost (Can$)	Total Net Book Cost (Can$)	Total Replacement Cost (Can$)	TCA Reporting
	TCA Report Burnaby	City Municipality of Burnaby	City	2/19/2013	22000000	18200000	3450000	Completed
	TCA Report Comox	Comox	Town	2/22/2013	18100000	16470000	2075000	Completed
	TCA Report Harrison Hot Spring	Harrison Hot Springs Municipality	Village	1/22/2013	5100000	4525000	339000	Completed
	TCA Report Highlands	District Municipality of Highlands	District	2/13/2013	9150000	6910000	575000	Completed
	TCA Report Ladysmith	Municipality of Ladysmith	Town	2/13/2013	16000000	7990000	2150000	Completed
	TCA Report Lions Bay	Lions Bay	Village	2/7/2013	4004000	3820000	304000	Completed
	TCA Report North Vancouver	North Vancouver	District	1/20/2013	11300000	9640000	860000	Completed
	TCA Report Pemberton	Village Municipality of Pemberton	Village	2/1/2013	4250000	3725000	427000	Completed
	TCA Report Richmond	City Municipality of Richmond	City	1/10/2013	20200000	16000000	3000000	Completed
	TCA Report Sidney	Town Municipality of Sidney	Town	8/21/2013	14400000	8650000	1075000	Completed
	TCA Report Squamish	District Municipality of Squamish	District	1/13/2013	10195000	3705000	695000	Completed
	TCA Report Surrey	City Municipality of Surrey	City	1/15/2013	41150000	38500000	3680000	Completed

Add document

Figure 9-14 A set of ten tangible capital asset reports

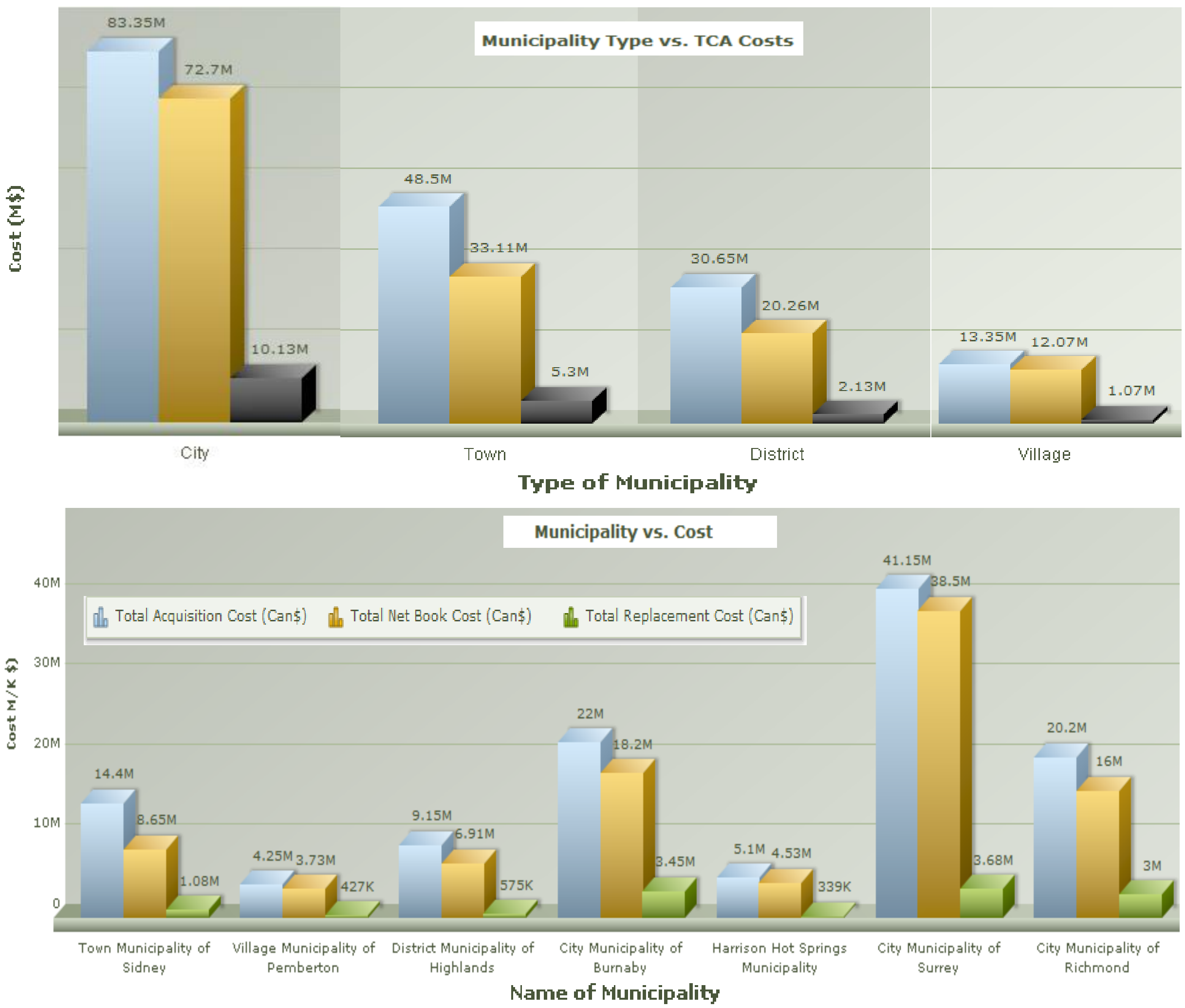


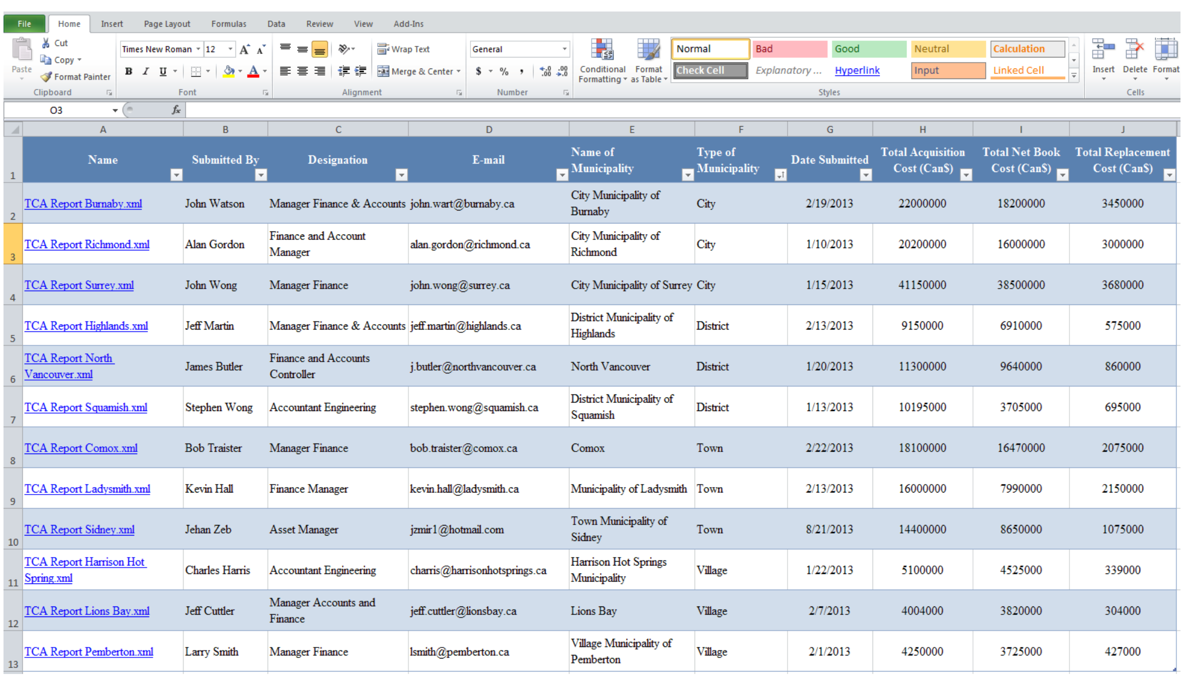
Figure 9-15 Real time charts development for the tangible capital asset list

The upper chart—municipality vs. cost was created to represent the name of the municipality on the x-axis and the cost (M/K $) on the y-axis. The cost includes: total acquisition cost, total net book cost, and total replacement cost of the infrastructure systems in million dollars (M $). This chart shows the three types of costs against each municipality. Similarly, the lower chart—municipality type vs. TCA costs was created between different types of municipalities and accumulated costs (M $).

This chart shows the total acquisition, net book value, and replacement costs against each type of municipality: city, town, district and village. The acquisition, net book, and replacement costs shown in the chart are the average of all the respective costs for a specific type of municipality. This chart gives an overall idea at a very abstract level about the replacement cost requirements in each type of municipality. Decision makers can allocate funds based these requirements without going into the detail analysis. These graphs are totally automated and each time when a TCA report is added or deleted, these charts are updated accordingly in real-time. These chart information can be filtered at any time using the dynamic filter functionality. For instance, the provincial government may want to see the TCA information for only city municipalities. The interactive nature of these charts makes it easy to change the shape, color, and format any time a user needs exploiting the edit chart functionality. The chart can be exported or imported in a variety of formats any time a requirement warrants.

9.5.8 Action 8—Analyze the TCA Information

The set of TCA reports received from city, town, district, town, and village municipalities can be analyzed using the MS Excel or Excel Services within the SharePoint Environment. All the list items that need to be analyzed were exported to Excel using "Export to Excel" functionality. All the list items in AI&CAR/TCA MTs library were selected and exported as MS Excel Web Query File. The file with "iqy" extension was saved on the local machine and was opened using the MS Excel for further analysis. A simple export that lists the items in Excel is shown in Figure 9-16.



Name	Submitted By	Designation	E-mail	Name of Municipality	Type of Municipality	Date Submitted	Total Acquisition Cost (Can$)	Total Net Book Cost (Can$)	Total Replacement Cost (Can$)
TCA Report Burnaby.xml	John Watson	Manager Finance & Accounts	john.wart@burnaby.ca	City Municipality of Burnaby	City	2/19/2013	22000000	18200000	3450000
TCA Report Richmond.xml	Alan Gordon	Finance and Account Manager	alan.gordon@richmond.ca	City Municipality of Richmond	City	1/10/2013	20200000	16000000	3000000
TCA Report Surrey.xml	John Wong	Manager Finance	john.wong@surrey.ca	City Municipality of Surrey	City	1/15/2013	41150000	38500000	3680000
TCA Report Highlands.xml	Jeff Martin	Manager Finance & Accounts	jeff.martin@highlands.ca	District Municipality of Highlands	District	2/13/2013	9150000	6910000	575000
TCA Report North Vancouver.xml	James Butler	Finance and Accounts Controller	j.butler@northvancouver.ca	North Vancouver	District	1/20/2013	11300000	9640000	860000
TCA Report Squamish.xml	Stephen Wong	Accountant Engineering	stephen.wong@squamish.ca	District Municipality of Squamish	District	1/13/2013	10195000	3705000	695000
TCA Report Comox.xml	Bob Traister	Manager Finance	bob.traister@comox.ca	Comox	Town	2/22/2013	18100000	16470000	2075000
TCA Report Ladysmith.xml	Kevin Hall	Finance Manager	kevin.hall@ladysmith.ca	Municipality of Ladysmith	Town	2/13/2013	16000000	7990000	2150000
TCA Report Sidney.xml	Jehan Zeb	Asset Manager	jzmir1@hotmail.com	Town Municipality of Sidney	Town	8/21/2013	14400000	8650000	1075000
TCA Report Harrison Hot Spring.xml	Charles Harris	Accountant Engineering	charris@harrisonhotsprings.ca	Harrison Hot Springs Municipality	Village	1/22/2013	5100000	4525000	339000
TCA Report Lions Bay.xml	Jeff Cuttler	Manager Accounts and Finance	jeff.cuttler@lionsbay.ca	Lions Bay	Village	2/7/2013	4004000	3820000	304000
TCA Report Pemberton.xml	Larry Smith	Manager Finance	lsmith@pemberton.ca	Village Municipality of Pemberton	Village	2/1/2013	4250000	3725000	427000

Figure 9-16 Excel web query file is exported and opened in MS Excel

9.6 Conclusions

Municipal infrastructure organizations use diversified information systems to manage their infrastructure systems. These information systems generate the TCA data, which they need to exchange with other organizations for the smooth functioning of the infrastructure systems. There are some issue with the TCA data: heterogeneity of data format; inconsistent class description of data, and lack of component based categorization of data. Due to these issues, infrastructure organizations find it difficult to exchange the TCA data with other organizations. To address the issues, an ontology-supported Asset Information Integrator System (AIIS) was developed. The prototype AIIS implemented two main outcomes: (i) formalized transaction map, and (ii) message templates of a transaction specification developed for the AI&CAR/TCA Reporting. In this transaction, different municipalities send their TCA data to the provincial government for financial planning and budget allocation. The municipal experts identified this transaction as one of the transactions that has the greatest potential for IT improvement.

The proposed system was developed using a four-step methodology. *Create the system website and a library*—a website was created for the proposed AIIS using the SharePoint platform following a 4C approach: create a virtual directory on the Internal Information Server of the SharePoint; create a collection site, create websites, and create web pages. *Review and modify message templates*—the set of MTs already developed for the AI&CAR/TCA Reporting was reviewed for errors and site specific adjustments. These MTs were created as part of the specification development for the AI&CAR/TCA Reporting. The MTs represent header information section and a payload information. The information represented in the header information section was captured from the Transaction Domain Ontology and the information represented in the payload information section was captured from the Tangible Capital Asset Ontology. Both the ontologies were briefly introduced in this chapter. *Design and configure workflow*—the workflow is an automated business process that was designed based on the transaction map developed for the AI&CAR/TCA Reporting. Following designing the workflow, it was then configured through adding some rules to the workflow. *Define/add functionalities*—a set of functionalities were added finally in the proposed AIIS.

The AIIS was applied in the domain of infrastructure management to demonstrate how the experts from different municipalities will use the system while exchanging the TCA data with the provincial government. The whole idea was to explicitly explain how a user will accomplish a specific action while using the AIIS. The proposed AIIS will enable experts from different municipalities to exchange the TCA information effectively and efficiently due to implementation of the formalized message templates developed based on the knowledge represented in the two ontologies created as part of this research work. The ontology-based formalization of the MTs for the AI&CAR/TCA Reporting addresses the issues of TCA data heterogeneity and inconsistency while also makes them computer interpretable, which leads to time savings. The built-in search engine and history services in the AIIS would enable experts to search a transaction and track its history efficiently. The real-time visualization of the TCA data will help in efficient decision making.

Chapter 10 Conclusions, Contributions, and Recommendations

10.1 Introduction

This chapter describes the conclusions, contributions, implications, limitations, and recommendations for future research work. A brief description of the conclusions and contributions is organized according to the four main objectives set-forth in this research work.

Objective 1—benchmark initiatives: includes a survey of the use of information technologies (IT) in the municipal infrastructure management—Objective 1 (a) described in Chapter 2, and development and application of an Infrastructure Management—Process Maturity Model (IM-PMM)—Objective 1 (b) explained in Chapter 3, to assess the degree to which work processes and communications are formalized in the domain of infrastructure management. The IT survey was successfully completed and the proposed IM-PMM was developed and applied.

Objective 2—build ontologies: two ontologies were developed as part of this research. The Transaction Domain Ontology (Trans_Dom_Onto)—Objective 2 (a) described in Chapter 4, represents the transaction knowledge required for the design, management, and implementation of transactions. The Tangible Capital Asset Ontology (TCA_Onto)—Objective 2 (b) discussed in Chapter 5, was built to represent the Tangible Capital Asset (TCA) knowledge (the components that make up infrastructure systems) to support the design of transactions in IT systems, in particular, the Asset Inventory and Condition Assessment Reporting/Tangible Capital Asset (AI&CAR/TCA) Reporting.

Objective 3—develop TFP: the protocol was developed from a conceptual perspective—TFP Specification—Objective 3 (a) elucidated in Chapter 6 that outlines procedures for designing formal transactions, and a practical perspective—TFP Tool—Objective 3 (b) depicted in Chapter 7 that provides a set of forms and guidance for transaction development personnel to use the TFP.

Objective 4—develop, manage (i.e. archive), and implement transaction specifications: the AI&CAR/TCA Reporting transaction specification—Objective 4 (a)) was developed first to demonstrate the application of the TFP Tool. This specification was managed (i.e. archived) in a prototype Infrastructure Transaction Management Portal (ITMP)—Objective 4 (b) described in Chapter 8). The AI&CAR/TCA Reporting transaction was then implemented in a prototype Asset Information Integrator System (AIIS)—Objective 4 (c) described in Chapter 9).

In addition, this chapter discusses the theoretical and practical implications in terms of the contribution of this research work to the theory and practice respectively. The limitations and future extensions of this research work are also explained towards the end of the chapter.

10.2 Objective 1—Benchmark Initiatives

The benchmarking initiative was developed to address research questions one and two; therefore, this objective was divided into two sub-objectives. The first research question, "what transactions are candidates to formalize?", was addressed through conducting a survey to benchmark the use of IT in infrastructure management and identify transactions that have the greatest potential for IT improvement. The second research question, "how to assess transaction formalization?" was addressed through the development and application of the proposed Infrastructure Management-Process Maturity Model, (IM-PMM).

10.2.1 Benchmark IT Use and Identify Potential Transactions

A detailed discussion of the findings is presented in Chapter 2; briefly synthesized as follows:

Benchmark IT use—general IT use was benchmarked at the municipality level and department level. At the municipal level, the use of diversified software was recorded, which was grouped into five categories: planning and scheduling, design, finance and accounting, management, and monitoring. Similarly, at the engineering/public works department, the use of IT was benchmarked for six sub-processes of the asset maintenance management planning work function. For all the six sub-processes, the use of 16 different software applications was recorded, with Excel being used the most due to low cost, easy availability, convenience in use, and broad applicability.

The use of IT was also benchmarked in various city and district municipalities. The results indicated that the use of software in city municipalities was more than district municipalities due to availability of more funds, human resources, and technical expertise with the city municipalities. Moreover, the use of different communication channels was explored at the municipality and department levels. Fourteen communication channels were in use at the municipal level; with E-mail, telephone, and face-to-face meetings as the main communication channels used for information exchange. At the engineering/public works department level, a server-based channel was used as the main channel in addition to E-mail, telephone, and face-to-face meetings. These results indicated that information was exchanged in an unstructured, manual, and ad hoc basis, suggesting the requirement for a more formalized computer-to-computer based exchange of information.

Identification of transactions for IT improvement—this sub-objective of the IT survey directly answers the research question, "what transactions are candidates to formalize?" As a result of the survey, the respondents identified a set of transactions that have the greatest potential for IT improvement. The Asset Inventory and Condition Assessment Reporting/Tangible Capital Asset Reporting (AI&CAR/TCA Reporting) was selected for IT improvement because of its high cost, complexity, manual-based, and, most importantly, the newly imposed regulatory reporting requirements.

10.2.2 Develop and Apply Infrastructure Management-Process Maturity Model

The proposed IM-PMM was developed in response to the research question "why formalize transactions? or how to assess transaction formalization?" in order to assess the degree to which work processes and communications are defined in the domain of infrastructure management. The detailed findings of the development and application of the proposed IM-PMM is presented in Chapter 3 and a brief description is as follows:

Develop IM-PMM—the proposed model was developed in terms of the maturity assessment framework that defines four elements and five stages of maturity. The four elements are central to work process and communication formalization: process/transaction map definition, actor/actor role definition, information definition, and (when formalizing communication processes) message definition. The five maturity stages are: infancy, preliminary, reactive, proactive, and integrated. In the *infancy stage*, organizations are generally unaware of the idea that the work processes can be formalized. In the *preliminary stage*, organizations are aware of the importance of the elements represented in the maturity assessment framework; however, these are not defined and documented. In the *reactive stage*, organizations are fully aware of the importance of the work process and communication formalization; however, these elements are not defined and documented for any future use. In the *proactive stage*, the elements required in process and communication formalization are properly defined and documented for future use. Finally, in the *integrated stage*, the elements are defined, documented, and continuously monitored for improvement.

Apply IM-PMM—the proposed model was applied to assess the maturity of the six work processes of the asset maintenance management planning work function and two communications. These work processes and communications were selected for three reasons: compliance with newly imposed regulations, user requirements, and rarely investigated domain. The overall maturity assessment indicates that organizations are aware of the four elements required for the work process and communication formalization. They define work processes and communication, but on an ad hoc basis, which means the formalization is situation-specific, that it varies with the level of the skill set of the modeller and the type and location of a municipality, and that no documentation is recorded for future use in support of the process of formalization. The researcher believes that higher levels of work process and communication formalization are required in order to support the development and implementation of advanced computer-based collaboration and communication systems. Although no evidence was collected to support an assertion, the researcher hypothesizes that higher levels of process formalization would lead to better management practices and better outcomes for the civil infrastructure systems being studied.

10.3 Objective 2—Build Ontologies

The subsequent objectives were developed in response to the research question, “how to formalize and manage transactions?” The first part of this question, “how to formalize transactions?”, was responded through the development of an ontology-supported Transaction Formalism Protocol (TFP). The proposed TFP has two components: the ontology and protocol. The first part of the protocol deals with the development of the knowledge model that the protocol used to formalize transactions and is discussed in this section and the second part of the protocol deals with the development and application of the TFP and is discussed in the subsequent section. As part of this research work, two ontologies were developed: Transaction Domain Ontology and Tangible Capital Asset Ontology, discussed in the following sections.

10.3.1 Transaction Domain Ontology

The detailed description of the development of the Trans_Dom_Onto is presented in Chapter 4 and Appendix E, with a brief description as follows:

Ontology development—the Trans_Dom_Onto represents the transaction domain knowledge in terms of the taxonomies developed for the core concepts (i.e. transaction, message, actor, actor role, and information) and support concepts (i.e. attribute, modality, relationship, constraint, mechanism, and axiom).

Core concepts—are the main concepts that make up the transaction domain knowledge and are required for the design, management, and implementation of the transactions in infrastructure management. The *transaction taxonomy* represents different types of transactions based on two meta modalities: domain and communication transaction-modalities. The *domain transaction-modality* classifies transactions based on the engineering domain to which transactions belong. The *communication transaction-modality* classifies transactions based on how they are communicated between the collaborative partners. These modalities were further extended to have an elaborated modality-based taxonomy of transactions. The *message taxonomy* was created based on the following four modalities of the messages: The *function message-modality* describes messages based on the function they perform in a transaction or data exchange. The *formulation message-modality* classifies messages based on the mode of message creation. The *representation message-modality* classifies messages based on the level to which information is structured in a message. The *intelligent message-modality* categorizes messages based on the interpretational capabilities of the computer systems that send and receive the messages. The *actor and actor role taxonomy* was created based on *function role-modality*, which classifies actor roles based on diversified functions (i.e. roles) actor performs in the domain of infrastructure management both in the individual and organizational capacity. Moreover, a *taxonomy of information* was developed based on two modalities. The *header information-modality* classifies the message header information (meta information about a transaction or message), whereas the *payload information-modality* categories the message payload information (actual information content that the collaboration partners require to exchange in a given transaction.

Support concepts—support modeling of the core knowledge and enriches the knowledge representation. A detailed taxonomy of each of the support concepts was developed and represented in Appendix E.

Ontology evaluation—the Trans_Dom_Onto was evaluated using the criteria: consistency, conciseness, completeness, correctness, and clarity. The evaluation results indicate that the knowledge represented in the Trans_Dom_Onto is consistent, concise, complete, correct, and clear. A statistical analysis of the results was also conducted, which shows that the respondents were in universal agreement on the completeness, correctness, and clarity of the content represented in the Trans_Dom_Onto.

10.3.2 Tangible Capital Asset Ontology

The detailed description of the TCA_Onto is presented in Chapter 5, with a brief description is follows:

Ontology development—the TCA_Onto represents the TCA knowledge developed in the facility sector and four infrastructure sectors: transportation, water, wastewater, and solid waste management sector. The TCA knowledge was categorized based on four modalities: The *individual asset-modality* describes the TCAs based on the individual asset type. The *function asset-modality* classifies the TCAs based on the function that they perform in an infrastructure system. The *composition asset-modality* categories the TCAs based on their composition within the infrastructure system. The *sector asset-modality* classifies the TCAs based on the civil engineering sector to which they belong. In this research work, detailed taxonomies of the TCAs in the transportation, water, wastewater, and solid waste management sector were developed.

Ontology evaluation—the TCA_Onto was evaluated based on the following five criteria: consistency, conciseness, completeness, correctness, and clarity. The evaluation results indicate that the TCA_Onto is consistent, concise, complete, correct, and clear. The results were also tested for statistical significance, which indicate that the experts were in universal agreement on the completeness, correctness, and clarity of the knowledge captured in the TCA_Onto.

10.4 Objective 3—Develop Protocol

An ontology-supported TFP was developed in response to the research question "how to formalize transactions?" The first part of the protocol is discussed above; however, the second part of the protocol is discussed as follows.

10.4.1 Transaction Formalism Protocol Specification and Tool

The details of the TFP development are presented in Chapter 6 and 7; however, a brief description is as follows. The proposed TFP was developed from two perspectives: TFP Specification and TFP Tool.

TFP Specification—represents a theoretical perspective of the process of developing the protocol. The TFP Specification represents eight steps of the protocol as eight functions for which inputs, controls, mechanisms, tools/techniques, and outputs were defined. The eight-steps of the protocol are as follows. *Assess needs*—refers to identifying and selecting a transaction or a set of transactions for IT improvement. *Define As-is transaction map (TM)*—existing way of data exchange is defined to examine what and where the problems lies in the existing communication process. *Develop To-be TM*—improvements are made in the As-is TM and To-be TM is developed that incorporates one or all of three improvements: process, information, and mode improvements. *Collect information*—two types of information (header and payload information) are collected from the experts, case studies, reports, and documents. *Design message templates (MTs)*—message templates are designed based on the header and payload information captured in the previous step. *Review TM and MTs*—formalized TM and MTs are reviewed through experts to identify errors; if any, and make modification before it is adopted or implemented in applications. *Adopt and implement TM and MTs*—the finalized TM and MTs (i.e. transaction specification) is implemented in a web-based collaboration system using any platform like the SharePoint. *Monitor transaction specification*—the implemented transaction specification is monitored for continuous improvement.

TFP Tool—the TFP Tool includes a set of Excel-based forms and guidance developed for specific steps of the protocol. The guidance was developed for step 5 (design MT) and 7 (implement TM and MT), whereas forms were developed for all of the remaining 6 steps. Each form and guidance are discussed in detail in Chapter 7.

Evaluation—the TFP Specification was verified against a set of ten quality criteria: top-down approach, model-driven approach, iterative, platform non-restrictive, domain modeling, choreography modeling, information modeling, formal verification method, tool/techniques support and systematic approach. The verification results indicate that the TFP Specification incorporates all the quality characteristics. Similarly, the TFP Tool was validated through experts using the four criteria: feasibility, usability, usefulness, and generalizability. The validation results indicate that the TFP Tool was feasible, usable, useful, and generic. The validated data was tested for statistical significance, which indicated that the experts were in universal agreement on the feasibility, usability, usefulness, and generalizability of the proposed TFP Tool.

10.5 Objective 4—Develop, Manage, and Implement Transaction Specifications

This objective pertains to the development, management (i.e. archiving), and implementation of the transaction specifications. The development and implementation of specification were set-forth to demonstrate the applicability of the proposed approach. The management of transaction specification was set-forth in response to the research question, “how to manage transactions?”

10.5.1 Develop Transaction Specification

The transaction specification for the Asset Inventory and Condition Assessment Reporting/Tangible Capital Asset Reporting (AI&CAR/TCA Reporting—the case study transaction) was developed using the proposed ontology-supported TFP. The case study transaction was identified by experts in the municipal government through an IT survey conducted as part of this research work.

10.5.2 Manage Transaction Specification

This objective was set-forth in response to the research question “how to manage transactions? As a result, an Infrastructure Transaction Management Portal (ITMP) was developed as part of this research work. The detailed portal development is presented in Chapter 8; however, a brief description is as follows. The ITMP was developed using the SharePoint platform based on the transaction classes represented in the Trans_Dom_Onto. While developing the portal, a virtual directory was created first, which hosted the collection site, sub-sites, and web pages. The transaction specification developed for the AI&CAR/TCA Reporting was managed (i.e. archived) using the ITMP.

10.5.3 Implement Transaction Specification

The transaction specification developed for the AI&CAR/TCA Reporting was ultimately implemented in the prototype Asset Information Integrator System (AIIS), which was developed at the provincial government level and is supposed to receive the TCA reports from various municipalities for financial planning and budget allocation. The development and application of the AIIS are discussed in detail in Chapter 9; however, a brief description is as follows.

AIIS development—the AIIS was developed using the SharePoint platform. A virtual directory of the web-based AIIS was created first on the SharePoint server, wherein the collection site, website, and web pages were created. A form library—named the AI&CAR/TCA Reporting Message Templates—was created in a web page for storing instances of reports received from various municipalities. The transaction specification for the AI&CAR/TCA Reporting was designed and configured before implementing it in the application. Once the configuration was done, a set of functionalities was added: e.g. add or collect reports, edit reports, delete reports, download reports, search reports, navigate through system, integrate reports, compare reports, and visualize workflows and reports.

AIIS application—describes how the AIIS will be used for the AI&CAR/TCA Reporting between the provincial and municipal governments. The AIIS application was divided into four components: users, actions, defined MTs, and software. In the application of the AIIS, it was demonstrated that a set of actions (fill, send, receive, upload, process, visualize, and analyze) needed to be taken by both the users (municipal or provincial government) to successfully exchange the TCA report through a set of formalized MTs (i.e. the AI&CAR/TCA Reporting message template and the accept acknowledgment message template) using a specific software application (MS InfoPath Filler, MS Outlook, MS SharePoint, MS Excel, MS SharePoint Services, and MS Exchange).

10.6 Theoretical Implications and Research Contributions

The following are objective-wise theoretical implications in terms of major, medium, and minor contributions of this research work:

10.6.1 Contributions of Objective 1—Benchmarking Initiatives

The following sub-objectives of benchmarking initiatives are medium contributions of this research work:

- Survey of IT Use

  A survey was conducted to benchmark the use of IT in the domain of municipal infrastructure management and identify a set of transactions that has the greatest potential for IT improvement. In the past, IT surveys were rarely conducted in the domain of municipal infrastructure; therefore, this survey plays a vital role in (i) benchmarking the use of IT in this niche segment of the AEC/FM industry and (ii) identifying the AI&CAR/TCA Reporting as one the potential transactions for IT improvement. The results of the survey are a medium contribution of this research work.

- Development of IM-PMM

  The proposed maturity model was developed and applied to assess the level to which works processes and communications are formalized in the domain of infrastructure management. The proposed IM-PMM is different from the existing maturity models in the way that it focuses on if and how the processes were formalized, rather than how the processes were conducted and managed. The IM-PMM was successfully applied in the domain of infrastructure management and the results indicate that work processes and communications were performed on a manual and *ad hoc* basis. The development of IM-PMM is a medium contribution to the body of knowledge.

10.6.2 Contributions of Objective 2—Develop Ontologies

The two major contributions of this research work include the development of two ontologies.

- Development of Transaction Domain Ontology

  The Trans_Dom_Onto was developed as part of this research work to support the design, management, and implementation of transactions in the domain of infrastructure management. The Trans_Dom_Onto represents 420 classes and 1726 axioms that were developed based on the knowledge represented in the domain of interest. The Trans_Dom_Onto was evaluated and the results indicate that the knowledge represented in it was consistent, concise, complete, correct, and clear. The development of the Trans_Dom_Onto is a major contribution to the body of knowledge as it can be used in designing, managing and implementing transaction specifications.

- Development of Tangible Capital Asset Ontology

To support the design of message templates for AI&CAR/TCA Reporting transaction specification, a TCA_Onto was developed to represent the TCA knowledge in the transportation, water, wastewater, and solid waste management sectors. The TCA_Onto represents 345 classes and 1517 axioms, which was developed as an extension to the IPD-Onto. The knowledge represented in the TCA_Onto was used to define the payload information part of the message templates formalized for the AI&CAR/TCA Reporting. The TCA_Onto was evaluated and the results indicate that the knowledge represented in the ontology was consistent, concise, complete, correct, and clear. The researcher believes that the development of the TCA_Onto is a major contribution to the body of knowledge.

10.6.3 Contributions of Objective 3—Develop Protocol

- Develop Transaction Formalism Protocol Specification and Transaction Formalism Protocol Tool

The proposed TFP is an eight-step procedure developed to formalize transactions for IT based solutions in the domain of infrastructure management. The protocol was developed at two levels of abstraction: TFP Specification and TFP Tool. The proposed TFP Specification was verified against a set of modeling parameters and the TFP Tool was validated for feasibility, usability, usefulness and generalizability. The transaction development personnel will use the protocol to define transaction specifications effectively and efficiently. The development of the proposed protocol is a major contribution to the body of knowledge.

10.6.4 Contributions of Objective 4—Apply the Protocol to Develop, Manage, and Implementation Transaction Specifications

- Develop Transaction Specifications

A minor contribution of this research work is to develop a transaction specification of the AI&CAR/TCA Reporting, which was performed on a manual and *ad hoc* basis. This transaction was formally defined using the proposed protocol, which was stored in the proposed ITMP for future adoption or implementation in software applications.

- Develop Infrastructure Transaction Management Portal to Manage Transaction Specifications

The proposed ITMP was developed to manage formalized transactions, i.e. transaction specifications. All of the existing work process and transaction formalization standards focus on the development of the transaction specifications rather than managing it. The transaction development personnel will use the portal to store transaction specifications for implementation into software applications. The development of the portal is a medium contribution to the body of knowledge.

- Develop Asset Information Integrator System to Implement Transaction Specification

The proposed AIIS was developed to seamlessly exchange the TCA information between the provincial and municipal governments as part of the AI&CAR/TCA Reporting. The proposed system implements the AI&CAR/TCA Reporting transaction specification developed using the proposed ontology-supported TFP.

Industry experts will use the system for efficient and effective reporting of the TCA information. The development and application of the AIIS is a medium contribution to the body of knowledge.

10.7 Practical Implications of the Research

The following are objective-wise practical implication of this research work:

- Objective 1—Benchmark initiatives
    - The results of the IT survey can be used for; (i) policy formulation on the use of IT in municipal infrastructure management; (ii) monitoring and measuring future performance of the municipalities with respect to IT use; and (iii) selecting and implementing transactions in web-based collaboration systems.
    - The proposed IM-PMM enables the transaction development personnel to assess the degree to which work processes and communications are formalized in the area of infrastructure management in order to prioritize them for IT improvements.
- Objective 2—Build ontologies
    - The Trans_Dom_Onto can be used from three different perspectives. *Design perspective*—views the Trans_Dom_Onto as a dictionary of terms that the transaction development personnel use to define transactions throughout the eight steps of the proposed TFP Tool. The Trans_Dom_Onto explicitly defines the terms so that all parties have a common understanding of these terms and use them consistently. *Software application perspective*—the knowledge represented in Trans_Dom_Onto can be used to develop software applications. As part is this research work, the Trans_Dom_Onto was used to develop a web-based application—ITMP for the management of transaction specifications. *Implementation perspective*—the terms represented in the Trans_Dom_Onto can also be used to define header part of the MTs. The header information in the MTs developed for the AI&CAR/TCA reporting was captured from the Trans_Dom_Onto.
    - The TCA_Onto represents a complete set of the TCAs operated and managed at the municipality level; therefore, it can be used to define payload information part of the MTs for any potential transactions in the domain of infrastructure management. In addition, the TCA_Onto can be extended to develop a user-level ontologies in the domain of infrastructure management.
- Objective 3—Develop the protocol
    - The TFP Tool enables transaction-development personnel to develop transaction specifications effectively and efficiently for implementation into a variety of applications.
- Objective 4—Develop, manage, and implement transaction specifications
    - The transaction specification for the AI&CAR/TCA Reporting has already been developed as part of this research work; therefore, municipalities can easily adopt and implement it into applications.

- The development of the ITMP would enable the transaction development personnel to manage transaction specifications effectively and efficiently in a web-based repository resulting in space and time savings.
- The proposed AIIS would enable experts from different municipalities to exchange the TCA information with other organizations effectively and efficiently.

10.8 Limitations of the Research

The objective-wise limitations of this research work are as follows:

- Objective 1—Benchmark initiatives
  - The IT survey was limited to city and district municipalities as town and village municipalities did not respond to participate in the study.
  - The IT survey was limited to explore the use of IT in six work processes and two communications, while there are many other work processes and communications that can be examined to have a broad spectrum on the use of IT in infrastructure management.
  - The proposed IM-PMM was applied to only six work processes of the asset maintenance management planning work function and two communications in the domain of infrastructure management, which does not provide a holistic picture of the maturity assessments in the construction industry.
- Objective 2—Build ontologies
  - Limited representation of the bi-lateral and multi-lateral transactions under the collaboration-based transactions represented in the Trans_Dom_Onto, which needs to be extended to represent a complete set of collaboration transactions in the domain of infrastructure management
  - The knowledge represented in the TCA_Onto was limited to the facility, transportation, water, wastewater, and solid waste management and; therefore, it would not be able to support the design of MTs in other infrastructure sectors; e.g. electricity, gas, and telephone.
- Objective 3—Develop the protocol
  - The proposed TFP Tool is not fully automated and the transaction specifications are created manually using the Excel-based forms.
- Objective 4—Develop, manage, and implement transaction specifications
  - Presently, the ITMP is a prototype showing a limited number of sub-sites representing transaction classes, web pages, and different functionalities.
  - The complete data set represented in the MTs defined for the AI&CAR/TCA Reporting was not completely exported to Excel for analysis due to establishing data links manually, which was a time-consuming effort.

10.9 Recommendations for Future Research

The following are the objective-wise recommendations for the future research work:

- Objective 1—Benchmark initiatives
  - To have a holistic view of the IT use in the area of infrastructure management, it is recommended to carry out a national survey across the country that will cover various types of municipalities in different provinces and territorial regions. In addition, other work processes and communications should be examined to have a broad spectrum and realistic picture of the IT use in municipal infrastructure management.
  - The IM-PMM should be applied industry-wide, county-wide, department-wide, and process-wide to assess its generalizability
  - Also, two policy frameworks, one each for the city and district municipalities need to be developed. The strategies and policy recommendations contained in the respective frameworks should be able to address how, with the highest levels of process formalization, they can support the development and implementation of computer-based communication systems that lead to better management practices.
- Objective 2—Build ontologies
  - The Trans_Dom_Onto needs to be extended to incorporate a complete set of collaboration-based transactions in the domain of infrastructure management.
  - The TCA_Onto needs to be extended to incorporate the TCAs related to the electricity, gas, and the telephone infrastructure sector in order to support the design of MTs in these sectors.
- Objective 3—Develop the protocol
  - The TFP Tool is presently manual, which should be implemented in a more complete system information and workflow management system to create transaction specifications automatically.
  - The TFP Tool needs to be used in various industries to define diverse transactions to objectively measure its validity and generalization.
- Objective 4—Develop, manage, and implement transaction specifications
  - The transaction specification for the AI&CAR/TCA Reporting needs to be implemented in a full fledge web-based collaboration system in order to integrate the provincial and municipal governments.
  - The prototype ITMP needs to be transformed into a full fledge portal representing a complete set of transaction classes (subsites), web pages, and functionalities to accommodate the growing number of transaction specifications in future.
  - A TCA information dashboard should be added in the AIIS to automatically generate different types of graphs and reports that the provincial government needs for the analysis of the TCA information.

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Appendix A Analysis of Variance for the Use of Information Technology

A.1 Analysis of Variance for IT Survey

The analysis of variance (ANOVA) statistical analysis was carried out to assess the statistical significance of the IT use at the municipal level between different parameters. The results of the statistical analysis are presented in Table A-1, Table A-2, and Table A-3.

Table A-1 ANOVA for software use across different municipalities and work functions

	ANOVA: Two-Factor Without Replication					
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Rows	31.24479167	15	2.082986111	2.945280071	0.000362225	1.727387708
Columns	7.057291667	11	0.64157197	0.90716358	0.534895013	1.847078309
Error	116.6927083	165	0.707228535			
Total	154.9947917	191				

Table A-2 ANOVA for software use in the city and district municipalities

	ANOVA: Two-Factor Without Replication					
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Rows	187.46875	15	12.49791667	6.702793296	0.000338585	2.403447071
Columns	19.53125	1	19.53125	10.47486034	0.005534413	4.543077165
Error	27.96875	15	1.864583333			
Total	234.96875	31				

Table A-3 ANOVA for the use of different types of communication channels

	ANOVA: Two-Factor With Replication					
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Sample	16.07142857	1	16.07142857	40.90909091	6.34779E-07	4.195971819
Columns	140.9285714	13	10.84065934	27.59440559	1.5952E-12	2.088929347
Interaction	35.42857143	13	2.725274725	6.937062937	9.6125E-06	2.088929347
Within	11	28	0.392857143			
Total	203.4285714	55				

Appendix B Analysis of Variance for Maturity Assessments

B.1 Analysis of Variance for Work Processes and Communications Maturity

The analysis of variance (ANOVA) statistical analysis was carried out to assess the statistical significance of the work processes and communications maturity in the domain of infrastructure management against a set of parameters. The results of the statistical analysis are presented from Table B-1 through Table B-6.

Table B-1 ANOVA for work processes

	ANOVA: Two-Factor Without Replication					
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Rows	1.469911111	5	0.293982222	87.96010638	6.19491E-08	3.32583453
Columns	0.014977778	2	0.007488889	2.240691489	0.157018131	4.102821015
Error	0.033422222	10	0.003342222			
Total	1.518311111	17				

Table B-2 ANOVA for communications

	ANOVA: Two-Factor Without Replication					
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Rows	0.0171125	1	0.0171125	5.875536481	0.093836413	10.12796449
Columns	0.2776375	3	0.092545833	31.77539342	0.008964197	9.276628153
Error	0.0087375	3	0.0029125			
Total	0.3034875	7				

Table B-3 ANOVA for different elements in work processes

	ANOVA: Two-Factor Without Replication					
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Rows	1.469911111	5	0.293982222	87.96010638	6.19491E-08	3.32583453
Columns	0.014977778	2	0.007488889	2.240691489	0.157018131	4.102821015
Error	0.033422222	10	0.003342222			
Total	1.518311111	17				

Table B-4 ANOVA for different elements in communications

	ANOVA: Two-Factor Without Replication					
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Rows	0.0171125	1	0.0171125	5.875536481	0.093836413	10.12796449
Columns	0.2776375	3	0.092545833	31.77539342	0.008964197	9.276628153
Error	0.0087375	3	0.0029125			
Total	0.3034875	7				

Table B-5 ANOVA for work processes in the city and district municipalities

	ANOVA: Two-Factor With Replication					
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Sample	12.84027778	1	12.84027778	462.25	8.84243E-20	4.170876786
Columns	0.010416667	2	0.005208333	0.1875	0.829993176	3.315829501
Interaction	0.010416667	2	0.005208333	0.1875	0.829993176	3.315829501
Within	0.833333333	30	0.027777778			
Total	13.69444444	35				

Table B-6 ANOVA for communications in the city and district municipalities

	Anova: Two-Factor With Replication					
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Sample	10.20447531	1	10.20447531	3206.060606	1.05059E-11	5.317655072
Columns	0.14679784	3	0.048932613	15.37373737	0.001103119	4.066180551
Interaction	0.010416667	3	0.003472222	1.090909091	0.407017845	4.066180551
Within	0.025462963	8	0.00318287			
Total	10.38715278	15				

B.2 Sample Size Calculation

A stratified sampling procedure was used for this research work in which the whole population (BC municipalities) was divided into strata or smaller units based on their size and type. The whole BC municipalities were divided into four different strata: city, town, district, and village. From each strata, a sample size of five was selected for the survey using the following formula (CRS, 2012).

Sample size (ss) = Z^2 * (p) * (1-p)/c^2

Where:

Z = Z value (e.g. 1.96 for 95% confidence level)

p = Percentage picking a choice, expressed as decimal (0.5 used for sample size needed)

c = Confidence interval, expressed as decimal (e.g. 0.04 = ±4)

Correction for finite population

New ss = ss / 1+(ss-1)/pop

Where:

Pop = population

The University of
British Columbia

Appendix C IT Survey Questionnaire

Survey on the Use of Information Technologies in Municipal Infrastructure Management

QUESTIONNAIRE

&

GLOSSARY OF ITEMS

Investigators:

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The University of
British Columbia

Survey on the Use of Information Technologies in Municipal Infrastructure Management

QUESTIONNAIRE

For detailed information on this survey, please consult the consent form reflecting research background information. The survey is to be conducted through a combination of web-based and face to face interview methods using a structured questionnaire.

The questionnaire is divided into 3 parts with 8 sections, including:

- Part A—General information about key survey elements (Section-1);
- Part B—Benchmark IT use in infrastructure asset management (Sections-2 through 5); and
- Part C—Examine the methodology used to identify and define communication processes to enable IT solution (Sections-6 through 8).

Part A—(Section-1) of the questionnaire is web-based and respondents are requested to complete it electronically, whereas the questions in Part B and Part C are in hard copy, which the respondents will answer in a face-to-face interview.

All the questions are optional. The respondent's profile information, (name, position, contact information, and name of municipality) will be kept private. All other information will be available to the public; please do not provide any confidential or sensitive information.

NOTE: Definitions of the words in the questionnaire with bold, italic, and underline are presented in the glossary of terms at the end of this document. Also, the term communication process and transaction used in the questionnaire refers to the same thing.

PART A: General Information about Key Survey Elements

(Web Based Survey)

Part A of the questionnaire has one section that is to be conducted through web-based survey method. It collects general information about the key elements of the survey. The results will be used to correlate IT usage with different characteristic of these elements.

Section 1: Profile Information and Demographics

This section relates to the general profile information about key survey elements including;

- Respondent profile information
- Municipality profile information
- Engineering services/public works department profile information
- ***Infrastructure Systems*** profile information

Respondent IT Profile Information

1.1 Respondent Profile:

i. Respondent Name ______________________________

ii. Respondent Position/Designation/Title ______________________________

iii. Respondent Contact Information Tel No. ______________________________

Fax No. ______________________________

E-mail: ______________________________

iv. Survey Date (Web Based/Interview Date) ______________________________

1.2 Municipality Profile

i. Name of the municipality ____

ii. Type of municipality. Please select one of the following _________________________

a. District b. City c. Town

d. Village e. Regional Municipality f. Others, please specify. _________________________

iii. How many people does the municipality serve? ____________________________

iv. How many ***Full Time Equivalent (FTE)*** employees work in the municipality? ______________________

1.3 Engineering Services/Public Works Department Profile:

i. Number of ***Full Time Equivalent (FTE)*** ***technical and support staff*** work in the Engineering Services/Public Work Department.

Technical Staff __________________ and ***Support Staff*** _______________________

ii. Number of ***Full Time Equivalent***, ***technical and support staff*** associated with the management of Water/Wastewater and Road Infrastructure Systems?

Water ***Technical Staff*** ________________ and ***Support Staff*** ________________

Wastewater ***Technical Staff*** ________________ and ***Support Staff*** ________________

Roads ***Technical Staff*** ________________ and ***Support Staff*** ________________

1.4 Water/Wastewater and Roads Infrastructure Systems Profile:

NOTE: Facilities (like pumping station, treatment plants, disposal facilities, bridges, etc.), are not included as part of these two types of Infrastructure Systems.

i. What is the current replacement cost (in $ million) of Water/Wastewater and Roads Infrastructure Systems managed by your municipality?

Infrastructure System Name	**Replacement Cost (in $ Million)**
a. Water	_____________________________
b. Wastewater	_____________________________
c. Roads	_____________________________

ii. What is the length of the Water, Wastewater, and Roads Infrastructure Systems in your municipality?

NOTE: Length is measured in linear units (km or meters) of infrastructure systems. For roads, it represents the total length of all gravel and paved roads with single, dual and even triple lane carriageway. If possible data related to each type of these roads can be documented under comments at the end of this question. It excludes curbs, gutters, sidewalks, street lighting, street trees, signs, road base and sub-base.

Infrastructure System Name	**Size (km)**
a. Water Infrastructure Systems including main and collection network	___________________
b. Wastewater Infrastructure Systems including main and distribution networks	___________________
c. Road Infrastructure System	___________________

iii. What is the average annual ***Capital Budget*** (in dollar million) of Water, Wastewater, and Road Infrastructure Systems in your municipality (over the past five years)?

Infrastructure System Name	**Annual *Capital Budget* (in $ Million)**
a. Water	______________________
b. Wastewater	______________________
c. Roads	______________________

iv. What is the average annual ***Maintenance Budget*** (in dollar million) of Water, Wastewater, and Roads Infrastructure Systems in your municipality over the past five years?

NOTE: Do not include operational budget.

Infrastructure System Name	**Annual *Maintenance Budget* (in $ Million)**
a. Water	______________________
b. Wastewater	______________________
c. Roads	______________________

v. What is the ***Maintenance Budget*** limit (in dollars million) of your municipality before it becomes ***Capital Expenditure***? ______________________

NOTE: Capital expenditure includes the cost of replacement of existing and growth related projects. Major rehabilitation is a capital expenditure and other preventive, corrective/reactive and routine maintenance will come under maintenance.

Comments If any:

____

____

____

1.5 Respondent IT Profile.

i. List the technical software you use while performing various ***Work Functions/ Processes*** as part of your job description. Please write the name(s) of the software in Table 1-5(i):

NOTE: Examples of technical software include; ***Computer Aided Design (e.g. AutoCAD)***, ***Geographic Information Systems (e.g. ESRI)***, ***Inventory Systems (e.g. Maximo)***, Planning Software—(e.g. P3, Primavera, MS Project), Software for e-business/e-procurement, ***Risk Analysis*** and Economic Analysis Software, etc.

Table 1-5(i) List Software Name(s)	
Software 1	
Software 2	
Software 3	
Software 4	
Software 5	
Software 6	
Software 7	
Software 8	
Software 9	
Software 10	

ii. Rate the use of the following ***Communication Means*** for exchanging information as part of your job description, with colleagues, clients or stakeholders. Please select all that applies in Table 1-5(ii).

NOTE: Definitions of the rating factors are:

Not Used Communication Means are those which have never been used

Little Used Communication Means are those which are used once per six months

Seldom Used Communication Means ate those which are used once per month

Occasionally Used Communication Means are those which are used once per week

Mainly Used Communication Means are those which are used once per day

Table 1-5(ii) Rate Communication Means Usage							
		Communication Means Usage Rating					
		Unable to Rate	Not Used Communication Means	Little Used Communication Mean(s)	Seldom Used Communication Mean(s)	Occasionaly Used Communication Mean(s)	Mainly Used Communication Mean(s)
	Communication Means	0	1	2	3	4	5
a.	Face to Face Meeting						
b.	Telephone						
c.	Fax						
d.	Postal Mail						
e.	Disc (Floppy/CD/Memory Stick) based Exchange						
f.	E-mail Channel						
g.	Instant Message						
h.	Audio Conferencing						
i.	Video Conferencing						
j.	Template based Exchange						
k.	Web Page based Exchange						
l.	***Server based Exchange***						
m.	***Privately Dedicated Networks***						
n.	***Computer to Computer Automated***						
o.	Other, please specify						

Comments if any:

PART B: Benchmark IT Use in *Infrastructure Asset Management*

Part B is divided into 4 Sections:

Section 2: Identify ***Information Technology (IT)*** uses in ***Infrastructure Asset Management***

2.1 Rate IT ability and list name(s) of the ***Work Functions/Processes*** you perform as part of your job description in Table 2-1 against each technical software identified in question 1-5(i) of the web based questionnaire.

NOTE:

a. The list of technical software shown in Table 2-1 is captured from question 1-5 (i) of the web based questionnaire. Examples of technical software include; ***Computer Aided Design (AutoCAD)***, ***Geographic Information Systems (ESRI)***, ***Inventory Systems (Maximo)***, Planning Software (P3, Primavera, MS Project), Software for e-business/e-procurement, ***Risk Analysis*** and Economic Analysis Software, etc.

b. There could be more than one ***Work Function/Process*** against each software

c. Example responses to the question are shown in row 1, 2, and 3 of Table 2-1.

Table 2-1 Rate IT ability and list Work Function(s) names against each software identified in Q 1-5(i)

	List of Technical Software identified in Q1-5(i)	IT Ability Rating				List Work Function(s)	
		Unable to Rate	Basic Know-how	Intermediate Know-how	Expert Know-how		
		0	1	2	3		
	Example: MS Project					i.	Project Planning and Scheduling
						ii.	
						iii.	
	Example: Maximo					i.	Inventory Management
						ii.	
						iii.	
	Example: AutoCAD					i.	Drafting and Designing
						ii.	
						iii.	
i.						i.	
						ii.	
						iii.	
ii.						i.	
						ii.	
						iii.	
iii.						i.	
						ii.	
						iii.	
iv.						i.	
						ii.	
						iii.	
v.						i.	
						ii.	
						iii.	
vi.						i.	
						ii.	
						iii.	
vii.						i.	
						ii.	
						iii.	
viii.						i.	
						ii.	

Comments if any:

2.2 List the names and other characteristics of the ***Information Systems*** used to accomplish six processes of the ***Asset Management Planning Work Function*** as shown in the following Table 2-2.

NOTE—various processes in the Asset Management Planning Work Function include; Asset ***Inventory*** Management; Asset Condition Assessment/Performance Analysis; Asset Service Life Analysis; Asset Life Cycle Cost Analysis; ***Asset Risk Analysis***; and Decision Making Analysis. Detailed characteristics of the Information Systems as well as its rating criteria are explained in the subsequent paragraphs. Please provide the following details in Table 2-2.

i. **Name of the Information System**—for instance, Excel or other type of Spreadsheet, Database (MS Access, Sequel), ***Computer Aided Design*** (CAD, i.e. AutoCAD), ***Geographic Information System (GIS, i.e. ESRI),*** Integrated System, Maps, Property Records, Record Drawings, Paper/Manual, Inventory Systems, Record Order Systems, Asset Life Cycle Cost Analysis software, Asset ***Risk Analysis*** Software and Decision Support Software.

ii. **Version—**represents the version of the information System.

iii. **System user—**refers to the personnel or ***roles*** that use or operate the Information System or application software. Please write the name and designation of the responsible personnel.

iv. **Extent of use—**it refers to the extent of the use of Information Systems or Application Software. Please select one of the following and enter in Table 2-2.

0. Unable to Rate	1. Never Use	2. Seldom Use
3. Occasional Use	4. Frequent Use	5. Always Use

v. **Ease of use—**captures the level of the ease of use of the Information System or Application Software used to perform a process as part of the ***Asset Maintenance Management Planning Work Function***. Please select one of the following in the Table 2-2.

0. Unable to Rate	1. Very Difficult	2. Difficult
3. Average	4. Easy	5. Very Easy

vi. **Performance satisfaction—**represents the level or extent to which you and your colleagues are satisfied with the performance of the information systems or software applications. Please select on the following in the Table 2-2.

0. Unable to Rate	1. Dissatisfied	2. Somewhat Dissatisfied
3. Neutral	4. Somewhat Satisfied	5. Very Satisfied

vi. **Issues with the system**—please record any issues or problems with the specific information systems or application software. For example, interoperability problems, obsolete version, and fewer required functionalities, etc.

		TABLE 2-2 Characteristics of Information System						
	AMMP Processes	i.	ii.	iii.	iv.	v.	vi.	vii.
		Name	Version	System User Name & Designation	Rate Extent of Use	Rate Ease of Use	Rate Performance Satisfaction	Issues with the System
Work Function - Asset Maintenance Management Planning (AMMP)	Asset Inventory Management							
	Asset Condition Assessment/ Performance Analysis							
	Asset Service Life Analysis							
	Asset Life Cycle Cost Analysis							
	Asset Risk Analysis							
	Decision Making Analysis							

Select one of the following and fill in columns iv, v, and vi.			
0	Unable to Rate	Unable to Rate	Unable to Rate
1	Never Use	Very Difficult	Dissatisfied
2	Seldom Use	Difficult	Somewhat Dissatisfied
3	Occasionally Use	Average	Neutral
4	Frequent Use	Easy	Somewhat Satisfied
5	Always Use	Very Easy	Very Satisfied

2.3 Are the six processes of the ***<u>Asset Maintenance Management Planning Work Function</u>*** defined in accordance with one of the following process definitions as shown in Table 2-3? Please select one of the following statements and tick "√" the field in the Table 2-3.

i. No answer (I am neither aware of this process nor know about process definition)

ii. Process definition for this process is not generally performed in our municipality

iii. Process definition for this process is carried out in an ad hoc way, where the individual(s) or role(s) completing the task largely determines for themselves how to perform the work.

iv. Process definition for this process is formally defined, documented, and carried out as a repeatable standardized process.

v. Process definition for this process is formally defined (as in option iii), and is regularly reviewed and monitored in order to make ongoing improvements to the process.

2.4 Are the roles defined in accordance with one of the following role definition, to accomplish each of these six processes of the ***<u>Asset Maintenance Management Planning Work Function,</u>*** as is shown Table 2-3? Please select one of the following statements and tick "√" the field in the Table 2-3.

i. No answer (I am neither aware of this process nor know about process definition)

ii. Role definition for this process is not generally performed in our municipality

iii. Role definition for this process is carried out in an ad hoc way, where the individual(s) or role(s) completing the task largely determines for themselves as who is responsible to perform the work.

iv. Role definition for this process is formally defined and documented so that it could be used as repeated and standardized roles.

v. Role definition for this process is formally defined (as in option iii), and is regularly reviewed and monitored in order to make ongoing improvements to the role definition.

2.5 Is the input or output information defined/specified for each of the six processes of the ***<u>Asset Maintenance Management Planning Work Function</u>*** in accordance with the following information definition as shown in Table 2-3? Please select one of the following statements and tick "√" the field in the Table 2-3.

NOTE: For instance, in asset inventory management process, input information refers "to the information that is required to be stored in the inventory system, whereas the output information refers "to the information in the form of table reflecting the infrastructure inventory".

i. No answer (I am neither aware of this process nor know about information definition)

ii. Information definition for this process is not generally performed in our municipality

iii. Information definition for this process is carried out in an ad hoc way, where the individual(s) or role(s) completing the task largely determines for themselves as which information is required to accomplish the work.

iv. Information definition for this process is formally defined and documented so that it could be used as repeated and standardized information.

v. Information definition for this process is formally defined (as in option iii), and is regularly reviewed and monitored in order to make ongoing improvements to the information definition.

TABLE 2-3 Process, Roles, and Information Definition

Work Function - Asset Maintenance Management Planning (AMMP)		Q 2.3 - Process Definition					Q. 2.4 - Role Definition					Q. 2.5 - Information Definition				
		Neither aware of the process nor know about process definition	Not defined in this municipality	Defined in ad hoc way	Defined, documented & used as standardized processes	Defined, documented and monitored for improvement	Neither aware of the process nor know about Role definition	Not defined in this municipality	Defined in ad hoc way	Defined, documented & used as standardized roles	Defined, documented and monitored for improvement	Neither aware of the process nor know about information definition	Not defined in this municipality	Defined in ad hoc way	Defined, documented & used as standardized information	Defined, documented and monitored for improvement
	AMMP Processes	i	ii	iii	iv	v	i	ii	iii	iv	v	i	ii	iii	iv	v
	Asset Inventory Management															
	Asset Condition Assessment/Performance															
	Asset Service Life Analysis															
	Asset Life Cycle Cost Analysis															
	Asset Risk Analysis															
	Decision Making Analysis															

Section 3: ***<u>Benchmark</u>*** Information Technology (IT) Use for ***<u>Asset Information Reporting Process</u>*** (Work Function)

Table 3-1 collects data related to the following five headings:

3.1 Identify and describe the ***<u>Asset Information Reporting Process (Work Function)</u>***, the roles responsible, and communication channels/mediums used to exchange information in these processes?

NOTE—in this question, the focus is on how (communication channels), and by whom (responsible roles), the two types of Asset Information are exchanged, which includes the Asset Inventory Information and Asset Condition Assessment Information as shown in Table 3-1. Details of the Asset Information Reporting Process are explained in the following paragraphs. Please provide the following information in Table 3-1.

i. **Name of the reporting process**—refers to the name of the asset information reporting process. For instance, Inventory Information Reporting to Federal Government, Asset Inventory Information Reporting to Municipality Finance Department, Asset Condition Reporting to Pavement Design Engineer, etc.

ii. **Purpose of the reporting process**—describes the purpose or objective of the reporting process, for instance, the purpose of the Asset Inventory Information Reporting between the Engineering Services Department and Finance Department of the Municipality, is to request the funds for implementation. In addition, the purpose of the Asset Condition Assessment Information between Asset Manager and Design Engineer Infrastructure is to provide information to assess the residual life of the infrastructure to formulate rehabilitation strategies.

iii. **Sender's designation and organizational affiliation**—sender is the person or role who supplies or sends the asset information.

iv. **Receiver's designation and organizational affiliation**—receiver is the person or role who requests or receives information. For instance, Pavement Design Engineer (receiver) requests Municipal Asset Manager (supplier or sender) for the provision of latest asset condition assessment information.

v. **Communication channel**—refers to the means through which the Asset Inventory and Condition Assessment Information are exchanged between the sender and receiver role. Various channel types are given below Table 3-1. Please one or more channel types for a single process and fill in Column "V" of Table 3-1.

Table 3-1 Work Function - Asset Information Reporting Process

		i	ii	iii	iv	v
		Name of the Reporting Process	Purpose of the Reporting Process	Sender Designation/Organization	Receiver Designation/Organization	Communication Channel
Asset Information	Asset Inventory Information					
	Asset Condition Assessment/ Performance Information					

NOTE: Select one or more of the following channels/Mediums for a single process and fill in column "v" of the Table 3-1

a. Face to Face	d. Postal	g. Instant Message	j. Template based	m. Privately Dedicated Networks
b. Telephonic	e. Disc based	h. Audio Conferencing	k. Web page based	n. Computer to Computer Automated
c. Fax	f. E-mail	i. Video Conferencing	l. Server based	o. Other, please specify

3.2 How you rate the level of sophistication and extent of IT use in managing Water/Wastewater Infrastructure and Roads Systems at the Engineering Services/Public Works Department of your municipality, when compared with other public (government) and private organizations that own and operate similar systems? Please select one of the following ratings for "level of sophistication" and "extent of IT use in Table 3-2 below.

NOTE: "Lower" means IT use in municipalities is lower than other organizations, whereas "Higher" means IT use in municipalities is higher than other organizations

Tabe 3-2 Compare Level of Sophistication and Extent of IT Use with other Public and Private Organizations

		Level of Sophistication							Extent of IT Use						
		Unable to Rate	Extremely Lower	Lower	Same	Higher	Extremely Higher		Unable to Rate	Extremely Lower	Lower	Same	Higher	Extremely Higher	
Organizational Context		0	1	2	3	4	5		0	1	2	3	4	5	
i.	Compared with Public Organizations														
ii.	Compared with Private Organizations														

Section 4: Benchmark ***Asset Information Reporting Processes/Communication Processes***

4.1 Which of the following statements best describe the Asset Information Reporting/Communication Processes previously identified in Table 3-1? Select one of the following statements and fill in the Table 4-1.

i. No answer (I am neither aware of this processes nor know about its process definition)

ii. Process definition for this process is not generally performed in our municipality

iii. Process definition for this process is carried out in an ad hoc way, where the individual(s) or role(s) completing the task (i.e. exchanging the asset information) largely determines for themselves how to perform the work (i.e. exchange the asset information).

iv. Process definition for this process is formally defined, documented, and carried out as a repeatable standardized reporting/communication process.

v. Process definition for this process is formally defined (as in option iii), and is regularly reviewed and monitored in order to make ongoing improvements to the reporting/communication process.

4.2 Are the roles responsible for the exchange of the Asset Information Reporting/Communication Processes identified in Table 3-1? Select one of the following statements and fill in the Table 4-1.

i. No answer (I am neither aware of this process nor know about the role definition)

ii. Role definition for this process is not generally performed in our municipality

iii. Role definition for this process is carried out in an ad hoc way, where the individual(s) or role(s) completing the task (i.e. exchange the asset information) largely determines for themselves as who is responsible to perform the work (i.e. exchange the asset information).

iv. Role definition for this process is formally defined and documented so that it could be used as repeated and standardized roles.

v. Role definition for this process is formally defined (as in option iii), and is regularly reviewed and monitored in order to make ongoing improvements to the role definition.

4.3 Is the information that is required to be exchanged between the sender and receiver roles is defined for the Asset Information Reporting/Communication Processes identified in Table 3-1? Select one of the following statements and fill in the Table 4-1.

i. No answer (I am neither aware of this process nor know about information definition)

ii. Information definition for this process is not generally performed in our municipality

iii. Information definition for this process is carried out in an ad hoc way, where the individual(s) or role(s) completing the task (i.e. exchange the asset information) largely determines for themselves as which information is required to be exchanged to perform the work.

iv. Information definition for this process is formally defined and documented so that it could be used as repeated and standardized Information.

v. Information definition for this process is formally defined (as in option iii), and is regularly reviewed and monitored in order to make ongoing improvements to the information definition.

4.4 For message-based exchange of asset information between sender and receiver role, do you explicitly define and structure messages? Select one of the following statements and fill in the Table 4-1.

i. No answer (I am neither aware of this process nor know about message(s) definition)

ii. Message(s) definition for this process is not generally performed in our municipality

iii. Message(s) definition for this process is carried out in an ad hoc way, where the individual(s) or role(s) completing the task (i.e. exchanging the messages) largely determines for themselves the structure of the message.

iv. Message(s) definition for this process is formally defined, structured and documented so that it could be used as repeated and standardized structured templates.

v. Message(s) definition for this process is formally defined (as in option iii), and is regularly reviewed and monitored in order to make ongoing improvements to the structured templates.

TABLE 4-1 Process, Roles, Information, and Message Definition

Reporting Processes Identified in Table 3-1	Name of Processes from Table 3-1	Q 4.1 - Reporting Process Definition: i. Neither aware of the process nor know about process definition	ii. Not defined in this municipality	iii. Defined in ad hoc way	iv. Defined, documented & used as standardized processes	v. Defined, documented and monitored for improvement	Q 4.2 - Role Definition: i. Neither aware of the process nor know about role definition	ii. Not defined in this municipality	iii. Defined in ad hoc way	iv. Defined, documented & used as standardized roles	v. Defined, documented and monitored for improvement	Q. 4.3 - Information Definition: i. Neither aware of the process nor know about information definition	ii. Not defined in this municipality	iii. Defined in ad hoc way	iv. Defined, documented & used as standardized information	v. Defined, documented and monitored for improvement	Q 4.4 - Message Definition: i. Neither aware of the process nor know about message(s) definition	ii. Not defined in this municipality	iii. Defined in ad hoc way	iv. Defined, documented & used as standardized structured templates	v. Defined, documented and monitored for improvement
Asset Inventory Information Reporting Processes																					
Asset Condition Assessment Information Reporting Processes																					

Section 5: Benchmark ***Interoperability*** of the Infrastructure ***Information Systems***

5.1 Which of the following statements best describe the level of interoperability of the information systems at the Engineering Services/Public Works Department while exchanging Asset Inventory and Condition Assessment Information within the municipality and across the municipality to outside parties (government and private organizations)?

Please tick "√" only one of the following statements for "Within Municipality" and "Across Municipality" to outside parties" in Table 5-1.

Table 5-1 **Interoperability Levels**	**Within Municipality**	**Across Municipality**
i. Different Information Systems cannot exchange data. (**For instance,** CD/DVD/Flash Drive based exchange of a date file with incompatible format leading to non-opening of the file)		
ii. Different Information Systems can exchange data but cannot interpret and understand the meaning of the data content. (**For instance**, CD/DVD/Flash Drive based exchange of a date file in a compatible format leading to opening the file but still only human can interpret the date, like Ms Word file)		
iii. Different Information Systems can exchange data and also have the capabilities to interpret and understand the meaning of the data content. (**For instance**, CD/DVD/Flash Drive based exchange of a date file in a compatible format leading to opening the file while computers can also interpret the date, like AutoCAD Architecture and Autodesk Revit file)		

Comments:

PART C: Examine Methodology used to Identify and Define ***Communication Processes*** to enable IT Solutions

Part C is divided into the following three sections:

Section 6: Identify requirement for the development of a methodology to define and specify ***Communication Processes*** for IT deployment

6.1 Presently do you have a comprehensive systematic procedure/methodology to define ***Communication Processes***, (i.e. Asset Inventory and Condition Assessment Reporting Process between Asset Manager and Finance Department of Municipality or Public Sector Accounting Board, PSAB of the Federal Government **Or** any other ***Communication Processes***)? Please select one the following.

____

i. Yes ii. No.

NOTE: If you select “Yes” to Q 6.1, then proceed to Q 6.2, Q 6.3, Q. 6.4, Q. 6.5, and Q. 6.6, otherwise proceed to Section 7.

6.2 Which of the following statements best describes the methodology you use to define Asset Inventory and Condition Assessment Communication Processes or any other ***Communication Processes*** in the Engineering and Services Department of your Municipality. Please select one of the following in Table 6-1.

	Tabe 6-1 - Methodology Choices	Select one of the following
i.	A standard generic methodology developed by another regional, national, or international initiative.	
ii.	A localised methodology developed by your organization.	
iii.	A combination of both standard & localized methodologies.	

6.3 How you rate the ease of use of the methodology based on the following rating criteria? Please select one of the following ______________

0. Unable to Rate 1. Very Difficult 2. Difficult

3. Average 4. Easy 5. Very Easy

6.4 How many hours do you spend to define a ***Communication Process*** using this methodology? **(Hrs)**

i. Simple ***Communication Process*** between two parties ____________

ii. Complex ***Communication Process*** between more than two parties ____________

6.5 How many people are involved to define a ***Communication Process*** using this methodology? **No. of People**

i. Simple ***Communication Processes*** between two parties ____________

ii. Complex ***Communication Process*** between more than two parties ____________

6.6 Is the methodology affordable in terms of the cost incurred on identifying and defining the communication processes? Please select one of the following. ____________

i. Yes ii. No

Section 7: Identification of Potential ***Communication Processes*** in Water/Wastewater and Road Infrastructure Sectors for IT Improvement

7.1 Identify five (5) ***Communication Processes*** that take place between the Engineering Services/Public Works Department of your municipality with other departments and public/private organizations in the Water/Wastewater and Roads Infrastructure Sectors, which have the greatest potential for enhanced IT improvements. Please furnish the following information in Table 7-1.

i. **Name of the *Communication Processes***—refers to the names of the communication processes that need improvement in terms of enhanced IT deployment.

ii. **Purpose of the *Communication Processes***—refers to the purpose or objectives of these processes in terms of what is being accomplished as a result of executing these processes.

iii. **Names of parties involved in these *Communication Processes*—**captures names of the parties in terms of the designation of the personnel and their organizational affiliation.

iv. **Communication channel—**captures the means of communication being used for the exchange of information in these processes. Please write As-is channels used for the exchange of messages.

v. **Propose process improvement—**captures the proposed improvements (if any) that are required to improve the existing As-is process.

vi. **Key reasons—**represents the key factors and (or) problem(s)/issue(s) associated with those Communication Processes that requires IT solution, i.e. why an IT solution is required to improve the As-is situation of the Communication Processes. Some of the reasons for transaction IT improvement includes; (i) high frequency of a transaction; (ii) transaction importance/critically; (iii) organizational requirements to adopt IT based solution and so on.

Table 7-1 Identification of Communication Processes in Water/Wastewater and Roads Infrastructure Sectors for IT Improvement					
i	ii	iii	iv	v	vi
Name of the Communication Processes	Purpose of the Communication Processes	Names of Parties involved in the Communication Processes	Name of Present Communication Channel	Propose Process Improvements (If any)	Key Reasons - Why to Adopt IT Solution

Section 8: Defining Potential ***Communication Processes*** for IT Improvement

In this section, the respondent will define the ***Communication Processes*** identified in Section 7 that could benefit from an IT solution.

8.1 Define the ***Communication Processes*** identified in section 7 of the questionnaire based on the following parameters. Please provide the following information in Table 8-1.

i. **Name of the *communication processes*—**refers to the names of the communication processes that need improvement in terms of enhanced IT deployment. Just copy the name of the process from Table 7-1.

ii. **Numbers and sequence of *message*—**captures the messages that are exchanged between the parties in sequence to accomplish the communication process.

iii. **From—**is the sender of the message. Please write designation and organizational affiliation of the person sending the message.

iv. **To—**is the receiver of the message. Please write designation and organizational affiliation of the person receiving the message.

v. **Name of the *message*—**refers to the name of the individual message in the communication process that is exchanged between the parties

vi. **Purpose of the *message*—**represents the purpose or objectives of individual message being exchanged between the parties. It focuses on what is being accomplished as a result of sending and receiving these messages.

vii. **Information required**—captures the information that is required to be exchanged between the parties in each individual message of the communication process.

Table 8-1 Definition of Communication Processes in Water/Wastewater and Road Infrastructure Sectors for IT Improvement

i	ii		iii	iv	v
Name of the Communication Processes from Table 7-1	Messages		Name of the Message	Purpose of the Message	Information Required in each Message
	From	To			

Evaluation/Validation of the Transaction Identification and Definition

Please select one the following choices for questions 8.2 to 8.6 below.

Evaluation/Validation of the Transaction Process Identification and Definition

	Question	Unable to Rate (0)	Very Complex (1)	Complex (2)	Average (3)	Simple (4)	Very Simple (5)
8.2	How simple is the process of identification and definition of transaction for IT improvement as presented in section 7 and 8 of the questionnaire?						

	Question	Unable to Rate (0)	Very Difficult (1)	Difficult (2)	Average (3)	Easy (4)	Very Easy (5)
8.3	How easy is the process of identification and definition of transaction for IT improvement as presented in section 7 and 8 of the questionnaire?						

	Question	Unable to Rate (0)	Most Unuseful (1)	Very Unuseful (2)	Useful (3)	Very Useful (4)	Most Useful (5)
8.4	Did you produce useful results in terms of discovering, defining and improving transactions using the identification and definition process as presented in section 7 and 8 of the questionnaire?						

	Question	Unable to Rate (0)	Very Unaffordable (1)	Somewhat Unaffordable (2)	Affordable (3)	Somewhat Affordable (4)	Very Affordable (5)
8.5	Do the processes of transaction identification and definition for IT improvement as presented in section 7 and 8 of the questionnaire are affordable in relation to the person-hours spent?						

	Question	Unable to Rate (0)	Most Unapplicalbe (1)	Somewhat Unapplicable (2)	Applicable (3)	Somewhat Applicable (4)	Very Applicale (5)
8.6	Do the processes of transaction identification and definition for IT improvement as presented in section 7 and 8 of the questionnaire are relevant and applicable?						

Comments, If any:

Survey on the Use of Information Technologies in

Municipal Infrastructure Management

Glossary of Items

1. Ad hoc

It means for a specific purpose, case, or situation at hand. **OR** It is used to indicate something that is done at the time without planning ahead of time.

2. Assets

The physical component of a facility that has value, enables services to be provided, and has an economic service life of greater than 12 months.

3. Asset Management

A business process and decision-support framework that: (i) covers the extended service life of an asset; (ii.) draws from engineering as well as economics; and (iii) considers a diverse range of assets.

4. Asset Information Reporting Process (Work Function)

It refers to the responsibility or the meta level process that relates to the exchange of asset inventory and condition assessment information among different collaboration partners.

5. Asset Maintenance Management Planning Work Function

It refers to the responsibility or the meta level process in the domain of asset management, which relates to the analysis and selection of the maintenance alternatives as part of the planning activities.

6. Audio Conferencing

Audio conferencing enables two or more remote located partners participate in collaborative meetings simultaneously exploiting audio devices.

7. Benchmark

A protocol by which something can be measured or judged

8. Capital Budget

A plan to finance long-term outlays, such as for the construction of new fixed assets like infrastructure facilities and equipment, or for the replacement and rehabilitation of these assets.

9. Capital Expenditure

Funds spent for the acquisition or replacement/rehabilitation of a long-term asset

10. Communication Mean

Communication mean, is the medium through which messages are exchanged between parties.

11. Communication Process

Any exchange of information, communication, or interaction between different parties that make up the information flow can be described as a transaction. **OR** It is a pattern of activities that is performed by two actors: the initiator and the executer.

12. Computer Aided Drafting and Design (CAD)

Computer-aided drafting and design (CAD) is the use of computer technology for the drafting and design of real or virtual objects.

13. Computer to Computer

It refers to the communication process that is taking place among the computer system of collaboration partners with or without the aid of humans.

14. Computer to Computer Automated

It is a web based communication where computer exchanges information without human intervention. For example, an automated reply-email generated and sent by the computer saying that "I am out of the office till a certain date, please contact XYZ person in the meantime.

15. Memory Stick/Disk based Electronic Data Exchange

It refers to the exchange of information via files saved to Memory Stick, Floppy Disk, Compact Disk (CD), Digital Versatile Disk/Digital Video Disk (DVD), or equivalent.

16. Full Time Equivalent

It measures the employee’s involvement in an organization. A FTE of 1.0 and 0.5 means that the employee is equivalent to a full-time and half-time worker, respectively.

17. Geographic Information System (GIS)

A GIS integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information.

18. Information Technology (IT)

The study relates to the design, development, implementation, support, or management of computer-based information systems, particularly the software applications and computer hardware is referred to as Information Technology.

19. Information System

It refers to a system, whether automated or manual, that comprises people, machines, and/or methods organized to collect, process, transmit, and disseminate data that represent user information.

20. Infrastructure Systems

It is a an **i**nterconnected networks of the basic facilities, services, and installations needed for the functioning of a community or society, such as roads and communications systems, water and power lines, and public institutions; including, schools, post offices, and prisons, etc.

21. Instant Messaging

Instant messaging, also known as synchronous conferencing is a web based informal conversation between two or more parties, where instantaneous text messages are exchanged between the partners in real-time.

22. Interoperability

It refers to the ability of computer systems and organizations to exchange information and communicate with each other.

23. Inventory

An itemization of assets

24. Inventory System

A system used to enumerate inventory assets and record data associated with those assets.

25. Message

It refers to the information formulated in tangible (written) and intangible (verbal and non-verbal) forms that is exchanged between collaborating parties.

26. Privately Dedicated Network

It refers to the networking of the computers at the municipality level and using that network for the exchange of information.

27. Process

A systematic sequence of actions that combines inputs to produce an output

28. Risk Analysis

Risk Analysis is a technique designed to quantify the impact of uncertainty.

29. Role

It refers to the roles (designer, contractor, director etc.) that various actors (organizations and individuals) play in a given process.

30. Server Based Exchange

It is the File Transfer Protocol (FTP) based exchange of information, where large size data files are uploaded to a web server to share it with all stakeholders.

31. Support Staff

Support staff refers to the administrative staff, e.g. computer operators & other administrative positions, which assists the department of public work technical staff in undertaking various activities.

32. Technical Staff

Technical staff are the engineering related staff, including; managers, coordinators, and technologist who are directly related to the design, implementation and management of the infrastructure system.

33. Video Conferencing

A video conference is a set of interactive telecommunication technologies that enable two or more partners to interact via two-way video and audio transmissions simultaneously.

34. Work Function

It refers to the responsibility of an individual, department, or organization in a specific domain of the Architecture, Engineering, and Construction Industry.

35. Web based Exchange

It refers to the transmission mode that is based on the World Wide Web—the internet.

Appendix D Transaction Upper Ontology

D.1 Transaction Upper Ontology

As introduced previously, the highest level in overall ontology architecture is the upper ontology. In this research, a Transaction Upper Ontology (Trans_Upper_Onto), is defined that is derived largely from the upper ontologies of the previously introduced infrastructure ontologies. Figure D-1 shows the Trans_Upper_Onto, a modified version of the upper ontologies proposed by Osman (2007), El-Gohary (2008), and Zhang and El-Diraby (2009) in the domain of public infrastructure. The Trans_Upper_Onto is organized into core-concept and support-concept. The core concepts represent all the key generic concepts that form the basis of the transaction domain knowledge. The core concepts include: project, action, product and resources, characterized by trans-industry generality. According to Fox and Grüninger (1998), these concepts are the key entities in the production and services systems and manufacturing systems. The support concepts support modeling, organization, classification, and definition of the core concepts; including, attribute, modality, mechanism, constraint, and relationship. A brief introduction of these concepts follows.

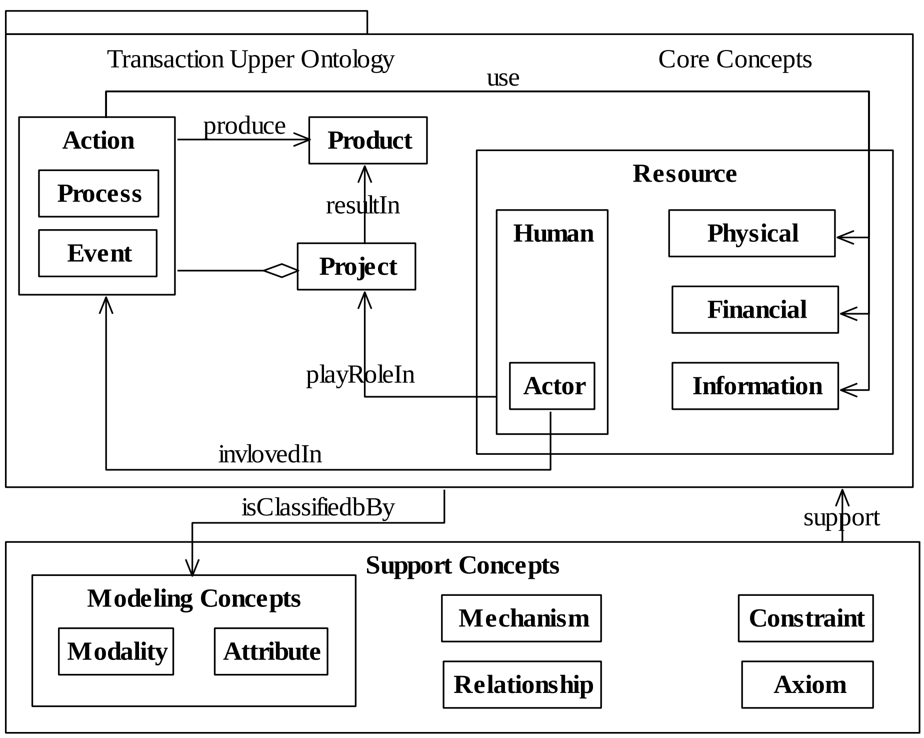

Figure D-1 Transaction upper ontology

D.1.1 Transaction Upper Ontology Core Concepts

The core concepts presented in Figure D-1 are described in the context of a specific project, where *the project* is defined as "a temporary endeavor undertaken to create unique products, services, or result" (PMI, 2008). The actor is an individual or organization that plays diversified roles and performs a variety of actions. According to El-Gohary

(2008), *action* is an umbrella concept representing processes and events. According to Becker *et al.* (1997), "process models are images of the logical and temporal order of functions." Therefore, these concepts are characterized and differentiated by the temporal scale. A *process* captures a set of activities that are undertaken to accomplish an objective over a period of time. An *event*, on the other hand, refers to the instantaneous occurrence of an activity (e.g. atomic transaction), where an instantaneous transfer of information from one role to another takes place. The execution of the action (process and event) in the project produces a *product*, which is classified as "knowledge, knowledge item, physical product, and decision" (Osman, 2007). The actor roles use resources to produce a product. The *resource* is something of value and is scarce, which includes physical resource (equipment, material, etc.), informational resource (software, drawing, contract, etc.), human resource (administrative and professional staff, skilled/unskilled workers etc.), and financial (owner's equity, loan from the bank, etc.).

D.1.2 Transaction Upper Ontology Support Concepts

The support concepts support the core concepts in relation to taxonomy development and establishing the relationships between the core concepts. These include: (i) modeling concepts (attribute and modality), (ii) mechanism, (iii) constraint, (iv) relationship, and (v) axiom. The modeling concepts support concept classification, whereas the mechanism, constraint, and relationship concepts enrich knowledge representation. An *attribute* is a characteristic, feature or property that describes a thing, entity or concept; whereas modality refers to a specific perspective or dimension through which a concept or entity is viewed and classified. *Modality* is defined as a characteristic that describes a thing and denotes its belonging to a particular group or category, (Osman, 2007 and El-Gohary, 2008). Modality brings multi-dimensionality to the knowledge. The concept of the modality is used in the Trans_Dom_Onto to ease categorization, management, and organization of the transaction concepts. According to Osman (2007) and El-Gohary (2008), the mechanism is an "umbrella concept representing guides, methods, and measures", which are extended to capture knowledge pertaining to the diversified mechanisms required to enable electronic transactions. *Mechanisms* are the means through which actor roles exchange information between each other. The *constraint* is a situation, circumstance, state, and/or obligation that limits the freedom of an action. According to Osman (2007), *axioms* specify definition of the concepts and constraints on their interpretation, whereas *relationships* are the associations between the concepts in the form of "is-a" or "part-of/composed-of" to enrich the knowledge representation.

Appendix E Transaction Domain Ontology

E.1 Transaction Domain Ontology Development

A ten-step procedure is used to develop the Transaction Domain Ontology (Trans_Dom_Onto) as shown in Figure E-1. Details of the steps are as follows.

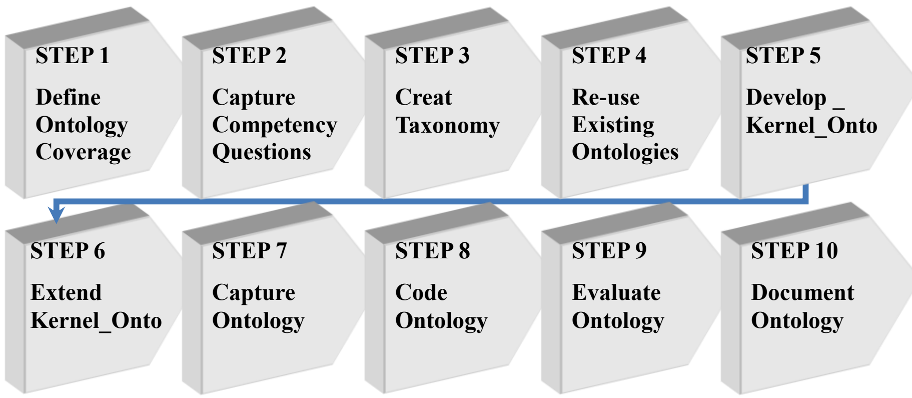

Figure E-1 Methodology to develop transaction domain ontology

E.1.1 Step 1—Define Ontology Coverage

This step defines the coverage of Trans_Dom_Onto in terms of its purpose, usability, and scope. The main *purpose* is to capture and represent transaction domain knowledge in the AEC/FM industry, specifically in the infrastructure sector to support the design, implementation, and management of transactions in order to enable message-based exchange of information between collaborating partners. The intended *uses* of the Trans_Dom_Onto are as follows.

Design perspective—views the Trans_Dom_Onto as a dictionary of terms that the transaction development personnel use to define transactions throughout the eight steps of the proposed form-based TFP Tool developed as part of this research work. The Trans_Dom_Onto explicitly defines the terms so that all parties have a common understanding of these terms and use them consistently. The information represented in the forms developed for various steps of the TFP Tool is based on the knowledge represented in the Trans_Dom_Onto.

Implementation perspective—the terms represented in the Trans_Dom_Onto are used to define header part of the message templates (MTs). The header information in the MTs developed for the AI&CAR/TCA Reporting is captured from the Trans_Dom_Onto.

Management perspective—focuses on how to manage standard transaction agreements/transaction specifications over the web. Once transaction specifications are created using the TFP, the next step is to archive or store it for future use. To ease access and retrieval of the transaction specifications, these should be grouped and stored in a web-based repository—Infrastructure Transaction Management Portal (ITMP). The portal is constructed based on the classes of transactions defined in the Trans_Dom_Onto as part of this research work.

Application ontology development—the Trans_Dom_Onto also provides a foundation of common concept definitions for future extensions as deemed necessary for creating application-level ontologies in support of specific software development efforts.

The primary *users* of the Trans_Dom_Onto are the software developers who will use the ontology to build transaction systems to support collaboration of the end users including; project-related partners, supply chain organizations in the construction industry, agencies like utility, government/non-governmental organizations and general users.

E.1.2 Step 2—Capture Competency Questions

A set of competency questions (CQs) were developed that the Trans_Dom_Onto should be able to answer. These CQs were developed based on the following detailed requirement analysis.

E.1.2.1 Requirement Analysis (RA)

A set of requirements guided the development of the Trans_Dom_Onto. To capture requirements for the Trans_Dom_Onto, an extensive literature review of the state-of-the-art standards, ontologies, process models and other related classifications were conducted to analyze and understand how others have modelled various aspects of the domain of interest (i.e. transaction formalism).

The concepts represented in the standards, ontologies, and models were divided into core and support concepts. The *core concepts* represent the main knowledge required for the design, implementation, and management of transactions. The *support concepts* represent the modeling concepts required to model the core knowledge. To capture core and support concepts for the Trans_Dom_Kernel_Onto and Trans_Dom_Onto, diversified references were reviewed and organized according to three groups as shown in Table E-1.

Based on the analysis of the core concepts, following four requirements were captured in the development of the transaction ontology.

i. The ontology should capture the transaction concept and its extensions.

ii. The ontology should reflect the concept of message/message template and its extensions.

iii. The ontology should represent the concept of actor and actor role and its extensions.

iv. The ontology should reflect the information concept and its extensions.

Based on the analysis of support/modeling concepts following four requirements were captured.

v. The ontology needs to reflect the attributes and modalities of various concepts.

vi. The ontology needs to represent mechanism and its extensions.

vii. The ontology needs to model transaction constraints.

viii. The ontology needs to capture the notion of generalization–specialization and composition–aggregation in terms of classification and decomposition of concepts.

Table E-1 Requirement analysis

	References →	Standards					Ontologies								Models/Papers						
	Concepts	(RossettaNet, 2002)	(ISO-ebXML, 2004-05)	(IAI-IDM, 2007)	(VISI, 2007)	bcXML (Lima et. al. 2003 & eConstruct, 2002)	REA Onto (Gailly el. al. 2007)	Open-edi Ontology (ISO, 2006)	COGNOS Taxonomy (El-Diraby et. al. 2005)	Feature Ontology (Staub-French et. al. 2003)	Infra. Product Ontology, IPD-Onto (Osman, 2007)	IC Process Ontology, IC-Pro-Onto (ElGohary, 2008)	Actors Ontology (Zhang and El-Diraby, 2009)	InteliGrid Ontologies (Gehri el. al. 2006)	Comm. Taxonomy (Anumba and Evuomwan, 1999)	Media Types (Network Working Group, 1996)	Transaction Formalism (Pouria, 2006)	OmniClass Classification System (OCCS, 2006)	(Froese, 1996a & Froese, 1992)	(Froese et. al. 1999)	CONCUR (Bjork et. al. 1999)
Core Concepts	Action	√	√		√					√		√		√					√		
	Process	√	√	√	√				√	√	√	√	√	√					√	√	√
	Event											√		√							
	Actor						√	√	√		√	√	√	√					√	√	√
	Actor-Role	√	√	√	√				√				√	√				√		√	√
	Message	√	√		√																
	Information	√	√	√	√								√			√		√			
	Project								√		√	√	√	√						√	√
	Product								√		√	√	√	√				√		√	√
	Resource						√	√	√	√	√	√	√	√				√	√	√	√
	Transaction	√	√		√		√	√									√				
	Std. Trans. Model	√	√	√	√																
	Project Specific Trans. Model		√	√	√																
	Structured Message/Templat	√	√		√																
	Message Choreography	√	√	√	√																
	Agreement	√	√		√		√	√													
Support/Modeling Concepts	Mechanism								√		√	√	√						√		
	Channel												√								
	Attributes	√	√		√	√	√	√	√	√	√	√	√	√		√	√			√	√
	Modality										√	√									
	Modality Family											√									
	Constraint										√	√	√								
	Relationship	√	√		√	√	√	√	√	√	√	√	√	√					√	√	√
	Classification	√	√		√	√	√	√	√	√	√	√	√	√	√	√	√	√		√	√
	Decomposition	√	√		√	√	√	√	√	√	√	√	√	√	√	√		√		√	√
	Axioms										√	√	√								

E.1.2.2 Develop Competency Questions

According to Gruninger and Fox (1995), these requirements guide formulation of the competency questions (CQs), which the ontology should be able to answer. For each requirement, a set of the following CQs were developed.

Competency questions for requirement #1 (transaction)—the ontology should capture the transaction concept and its extensions.

The following are the set of CQs developed for the communication transaction-modality.

i. Are transactions designed based on different design patterns?

ii. Are transactions defined based on the exchange of the physical, financial, and information resources?

iii. Is a transaction defined based on whether it is external or internal to the organization?

iv. Is a transaction formalized based on the location of transaction roles?

v. Are transactions defined based on the flow of information between persons and computer agents?

vi. Are transactions designed based on the response timings?

vii. Are transactions defined based on the means of transmission?

viii. Does transaction design incorporate control over transaction accessibility?

ix. Does transaction design incorporate transaction security?

The set of CQs developed for domain transaction-modality includes:

i. Are transactions designed and grouped according to bi-lateral and multi-lateral collaboration?

ii. Are transactions defined based on the sector or application area?

iii. Does transaction design incorporate different modes of the project delivery as one of the governing factors in the design of transactions?

iv. Does the Trans_Dom_Onto reflect the support processes defined in the IC-Pro-Onto?

Competency questions for requirement #2 (message)—the ontology should reflect the concept of message/message template and its extensions.

The set of CQs developed to satisfy requirement 2 are as follows.

i. Are messages defined based on the function they perform in an information exchange scenario?

ii. Are messages classified based on whether they are formulated as verbal or written messages?

iii. Does a message design incorporate the way information is to be represented in a message?

iv. Does a message design incorporate the level to which the information represented in the message is computer interpretable?

Competency questions for requirement #3 (actor and actor role)—the ontology should represent the concept of actor and actor role and its extensions.

To satisfy requirement #3, the following set of CQs was developed.

i. Is transaction role (sender/receiver role) represented in the actor taxonomy?

ii. Are the actor roles classified based on various core functions in the domain of infrastructure management?

iii. Is a transaction role related to a message?

iv. Is an actor related to a message instance?

Competency questions for requirement #4 (information)—the ontology should reflect the information concept and its extensions.

Following are the CQs developed for the information concept.

i. Does the ontology represent the header and payload information that is exchanged in a transaction?

ii. Does a message represent information?

iii. Is a message composed of header and payload information?

A set of CQ was developed for the header information.

i. Does the ontology represent the preamble, delivery, and service header information?

ii. Does the delivery header information classify header information based actor, actor role, temporal, and security information?

iii. Does the services header information classify header information based on message and transaction general information?

Similarly, a set of CQs was developed for the payload information.

i. Does the payload information modality classify payload information based on the placement of the information in the message?

ii. Does the payload information modality classify payload information based on the way information is formulated in a message?

iii. Does the payload information modality classify payload information based on the mode through which information is transmitted between the collaboration partners?

Competency questions for requirement #5 (attribute and modality)—the ontology needs to reflect the attributes and modalities of various concepts.

The CQs formulated for the core concept transaction are as follows.

i. Does the ontology represent transaction function as a characteristic of a transaction?

ii. Does the ontology represent transaction dependency as a property of the transaction?

iii. Does the knowledge representation incorporate logical dependency as one of the attributes of a transaction?

iv. Does the geographic dependency characterize a transaction?

v. Does the ontology represent cyber dependency of a transaction as one of the primary ingredients for transaction design, implementation, and management?

vi. Does the ontology represent control attribute as one of the characteristics of a transaction?

vii. Does the ontology reflect variable and fixed costs of a transaction?

viii. Does the knowledge representation incorporate administrative and transmission costs of a transaction?

ix. Does the knowledge base incorporate transaction efficiency as one of the performance characteristics of a transaction?

Similarly CQs were developed to create a taxonomy of information attributes.

i. Does the ontology incorporate attributes of the header information represented in the message templates?

ii. Does the ontology represent attributes of the payload information reflected in the message templates?

Competency questions for requirement #6 (mechanism)—the ontology needs to represent mechanism and its extensions.

The transaction mechanism includes: guides, methods, and measures and; therefore, CQ were developed separately for these three concepts.

- The CQ developed for guides are as follows:

  i. Does the mechanism taxonomy incorporate guides required to design, implement, and manage transactions?

  ii. Does the mechanism taxonomy represent different strategies that affects the design and implementation of transactions?

  iii. Does the mechanism taxonomy reflect best practices required for the design and implementation of electronic transaction?

- Similarly, following CQs were developed for transaction methods. The transaction method includes transaction exchange method and transaction archival method. The transaction exchange method is the means (transaction channel) through which information is exchanged between the parties whereas transaction archival method refers to the steps required to archive transactions as part of the transaction management.

  The CQs developed for transaction channels – (communication means)

  i. Does the mechanism taxonomy incorporate oral and written means of communication? How transaction messages are transmitted to partners in the AEC/FM industry?

  ii. Does the mechanism taxonomy represent electronic and non-electronic communication channels?

  The CQs developed for transaction management (i.e. archival)

i. Does the mechanism taxonomy represent transaction archival steps?

- The CQs developed for transaction measures are as follows.

i. Does the knowledge representation reflect objective and subjective metrics for the measurement of transaction efficiency?

Competency questions for requirement #7 (constraint)—the ontology needs to model transaction constraints.

i. Does the constraint taxonomy represent internal and external constraints hampering the design and implementation of transactions?

Competency questions for requirement #8 (relationship)—the ontology needs to capture the notion of generalization–specialization and composition–aggregation in terms of classification and decomposition of concepts.

i. Does the transaction domain knowledge represents hierarchal (is-a) and association relationships?

ii. Does the relationship taxonomy incorporate aggregation-composition relationships?

E.1.3 Step 3—Create/Generate Taxonomy

In this step, a preliminary transaction taxonomy was generated using a four step approach: *first,* concepts were captured from state-of-the-art standards, ontologies and models; *second,* concepts were compared to identify synonymous concepts to avoid duplication; *third*, a preliminary categorization of the concepts was developed; and *fourth*, an informal taxonomy was created.

E.1.4 Step 4—Reuse Existing Ontologies

During the development of the Trans_Dom_Onto, use was made of the existing ontologies in the domain of infrastructure management. The term "use" refers to establishing links between the existing and new ontology (i.e Trans_Dom_Onto), in contrast to merging some or all of an existing ontology. Therefore, a link was established between the Trans_Dom_Onto and the three infrastructure ontologies in order to re-use the concepts that have already been adequately defined there.

E.1.5 Step 5—Develop Transaction Domain Kernel Ontology

The Trans_Dom_Onto, as a domain Ontology constructed using the concepts defined in the upper ontology, was further decomposed into a central kernel ontology along with a series of extension domain Ontologies. The purpose of the Transaction Domain Kernel Ontology (Trans_Dom_Kernel_Onto), was to capture a lean structure to represent a holistic view of the transaction domain knowledge, enhance comprehension, ease concept extensions and better organize the knowledge. Similar to the Trans_Upper_Onto, the knowledge in the Trans_Dom_Kernel_Onto was also organized into core-concept and support-concept as shown in Figure E-2 Transaction domain kernel ontology.

E.1.5.1 Transaction Domain Kernel Ontology Core Concepts

The actor, actor role, message, information and transaction classes constitute the core concepts in the kernel ontology. In any given information exchange process, an actor participates in a transaction and plays different roles. Actor roles possess and control information, which they need to share or transfer in a transaction. Payload and header information are two types of information that are represented in either tangible (written) or intangible (verbal) form, commonly known as a message, which is part of a transaction and is transmitted between the actor roles in a given transaction. A message is instantiated in a given transaction, whereas the name of the actor is reflected in the message instance and the name of the actor role is reflected in the message. The definitions of the core concepts are as follows:

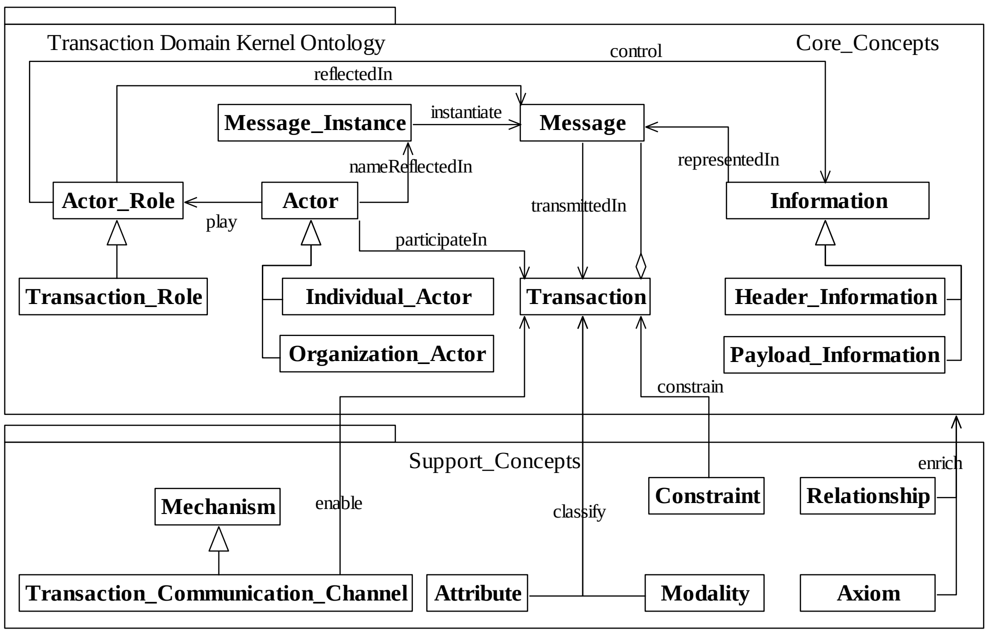

Figure E-2 Transaction domain kernel ontology

An *actor* can be one of two types: an individual—a human being, considered to be an indivisible entity, or an organization - a unique framework of authority within which persons act towards achieving overall common objectives (ISO, 2006). An *actor role* is defined as “a set of connected behaviors and attributes as conceptualized by actors in a given social position”, (Zhang and El-Diraby, 2009). In a transaction scenario, an actor plays the role of a sender or receiver (i.e. *transaction role*) through exchanging information in a transaction. *Information* is defined as data (a series of atomic and disconnected facts, statement of events or observation), processed, analyzed and co-related to a context to make it useful for the user. It is represented in a *message* formulated in tangible (written) or intangible (verbal and non-verbal) forms that are exchanged between collaborating partners, whereas a *message instance* is an instantaneous message accomplished in a given transaction. According to Pouria *et al.* (2002), any exchange of information, “communication or interaction between different parties that make up the information flow can be described as a *transaction*”. In this research work, *transaction* is defined as any communication or interaction between the sender and receiver roles that make up the information flow through a single or collection of a sequenced set of messages.

E.1.5.2 Transaction Domain Kernel Ontology Support Concepts

The support concepts encompass attribute, modality, mechanism, constraint, axiom, and relationship at a higher level of abstraction. The relationships between the core and support abstract concepts are established as described below. *Attribute and modality* both classifies the core concepts with specific focus on transaction classification. *Mechanism* refers to a transaction communication channel that an actor role uses to accomplish a transaction. A channel is a means of communication that enables the transmission of messages between the actor roles. A *constraint* is a situation, circumstance, state, and/or obligation that limits the freedom of an action in terms of transaction design and implementation. The *axioms* are explicit descriptions or declarations of the transaction domain knowledge using a formal language. According to Osman (2007), *relationships* are the associations between the concepts to enrich knowledge representation.

E.1.6 Step 6—Extend Transaction Domain Kernel Ontology

The core concepts and support concepts represented in the Trans_Dom_Kernel_Onto ontology were extended to develop detailed taxonomies. The taxonomies of the core concepts; transaction and message are described in Chapter 4; however, the remaining core concepts; actor/actor role and information and support concepts (e.g. attribute, mechanism, constraint, and relationship) are explained as follows.

E.1.6.1 Actor/Actor Role Taxonomy—Core Concept

Actors participate in transactions to exchange required information to accomplish certain activities. According to ISO (2006), the *actor* is either individual (who is a human and is an indivisible entity), or organization (that is a framework of authority within which actors play certain roles to achieve common objectives). Actors play certain roles in a given social context, and according to Zhang and El-Diraby (2009), *actor roles* are "a set of connected behaviors and attributes as conceptualized by actors in a given social position". These behaviors and attributes of roles change significantly with the given circumstances and the responsibility they accomplish in a specific context. For instance, an individual in the capacity of a civil engineer plays numerous roles like project manager (from a contracting firm), designer (from a consulting firm) and director (from a government department). For effective communication, actor roles need to be defined so that transaction messages are directed to the right role to avoid communication delays. According to FMI/CMAA (2003), unclear roles in a construction process are one of the main reasons of poor communication between collaboration partners. Actor/actor role taxonomy is developed based on function role modality as shown in Figure E-3.

E.1.6.1.1 Function Role Modality

The function role modality classifies actor roles based on the different functions actor roles performed in the domain of infrastructure management in both the individual (e.g. engineer role, manager role, coordinator role, etc.) and organizational (e.g. local government role, gas utility role, contractor role etc.) capacity. A set of the most important roles from the infrastructure management perspective are represented in the Tran_Dom_Onto; however, additional actor roles, if required, for the design of messages can be captured from the Actor Ontology.

Transaction role—is the role that actor plays in accomplishing a transaction or exchanging information in a transaction. It has two sub-classes: sender and receiver role. A *sender role* is defined as the role, the actor plays in transmitting a message to the receiving party in a transaction whereas the *receiver role* is defined as the role, the actor plays in collecting message in a transaction. A message represents the information that is required to be exchanged between the sender and receiver role to accomplish a transaction successfully. Collaborating partners play the role of a sender and receiver simultaneously in performing a transaction.

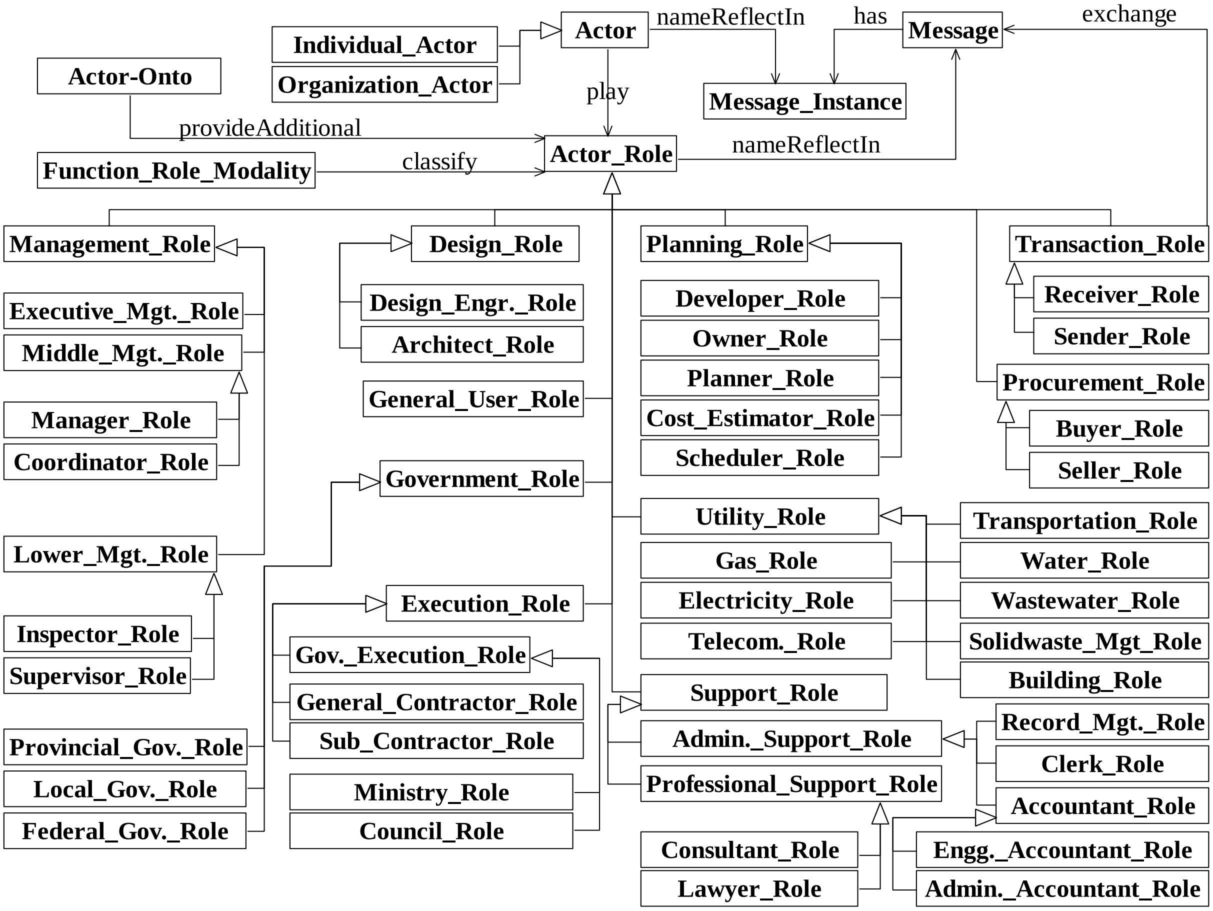

Figure E-3 Taxonomy of actor and actor roles

Transaction roles are closely associated with the concept of message and message instance. In a given atomic transaction (a solo exchange of information), a single message (representing required information) is transmitted between actor roles, which means a message is instantiated between the roles in that particular atomic transaction. A message represents actor and actor role information as part of the message meta data. A message reflects the name of the actor role and a message instance reflects the name of the actor.

Procurement role—is the role that actors play in buying and selling goods and materials required in a construction process. The actor plays these roles in the commercial transactions where some economic resource (money or equipment/material) is reciprocated between the buyer and seller roles. The procurement role has two types: buyer role and seller role. *Buyer role*—actor play in buying equipment and material to accomplish a construction process, whereas the *seller role*—actor plays in selling equipment and material.

Planning role—is the role that actor plays in planning, scheduling, estimating, and developing various activities or processes to manage infrastructure systems. It has the following sub-classes: developer role, owner role, planner role, cost estimator role*,* and scheduler role.

Utility role—refers to the role that actor plays in organizational capacity as an infrastructure management agency in the domain of infrastructure management, *or,* it is the role that actor plays in a departmental capacity as an infrastructure management department in the domain of infrastructure management. In the Trans_Dom_Onto, sub-classes of utility role are: transportation, water, wastewater, solid waste management, building, gas, electricity, and telecommunication utility roles.

Support role—is the role that actor plays to support working of administrative and technical departments in the domain of infrastructure management. It has two sub-classes: administrative and professional support role. *Administrative support role*—supports working of the administrative department in the domain of infrastructure management. It's sub-classes are: record management role, clerk role and account role. *Professional support role*—provides technical support for smooth operations of the technical department in the domain of infrastructure management. It's sub-classes are: consultant and lawyer role. Both of these roles provide technical support in the respective jurisdiction.

Design role—is the role that actor plays in designing infrastructure systems. It has two sub-classes: design engineer role and architect role. The design engineer role carries out structural design of the infrastructure systems, whereas the architect role carries out architectural design of the facilities.

General user role—refers to the role that actor plays in the form of general public in the domain of infrastructure management. For instance, general user is the public who send messages to the respective utility companies for the replacement of a faulty gas meter or power meter.

Government role—it is the role that actor plays as a government agency in organizational capacity. In the Trans_Dom_Onto, government role has three types: federal, provincial, and municipal government role. All the three roles are played at the federal, provincial, and municipal levels.

Execution role—is the role that actor plays to run the government and physically undertake or execute construction activities in the domain of infrastructure management. It has three sub-classes: government execution role, general contractor, and sub-contractor.

Management role—is the role that actor plays to manage design, construction, operation, and maintenance of the infrastructure systems and facilities. It has three types. *Executive management role*—is the top management that oversees policy matters and carry out decision-making for smooth operations of the infrastructure systems and facilities. *Middle management role*—manages operations of the infrastructure systems and facilities and its sub-classes are: manager and coordinator role. *Lower management role*—directly supervises operations of the infrastructure systems and facilities. It has two sub-classes: supervisor and inspector role.

E.1.6.2 Information Taxonomy—Core Concept

A transaction is successfully accomplished once information is exchanged or transferred between the parties involved in the communication. Information is an important element of a transaction. According to OCCS (2006), information is defined as "data referenced and utilized during the process of creating and sustaining the built environment." A transaction message represents two types of information: header and payload information. *Header information*—is meta information about a transaction or transaction message, whereas the *payload information*—is the actual information content that collaboration parties require to exchange in a given transaction. An information modality classifies header and payload information based on two perspectives: header information and payload information modality as shown in Figure E-4.

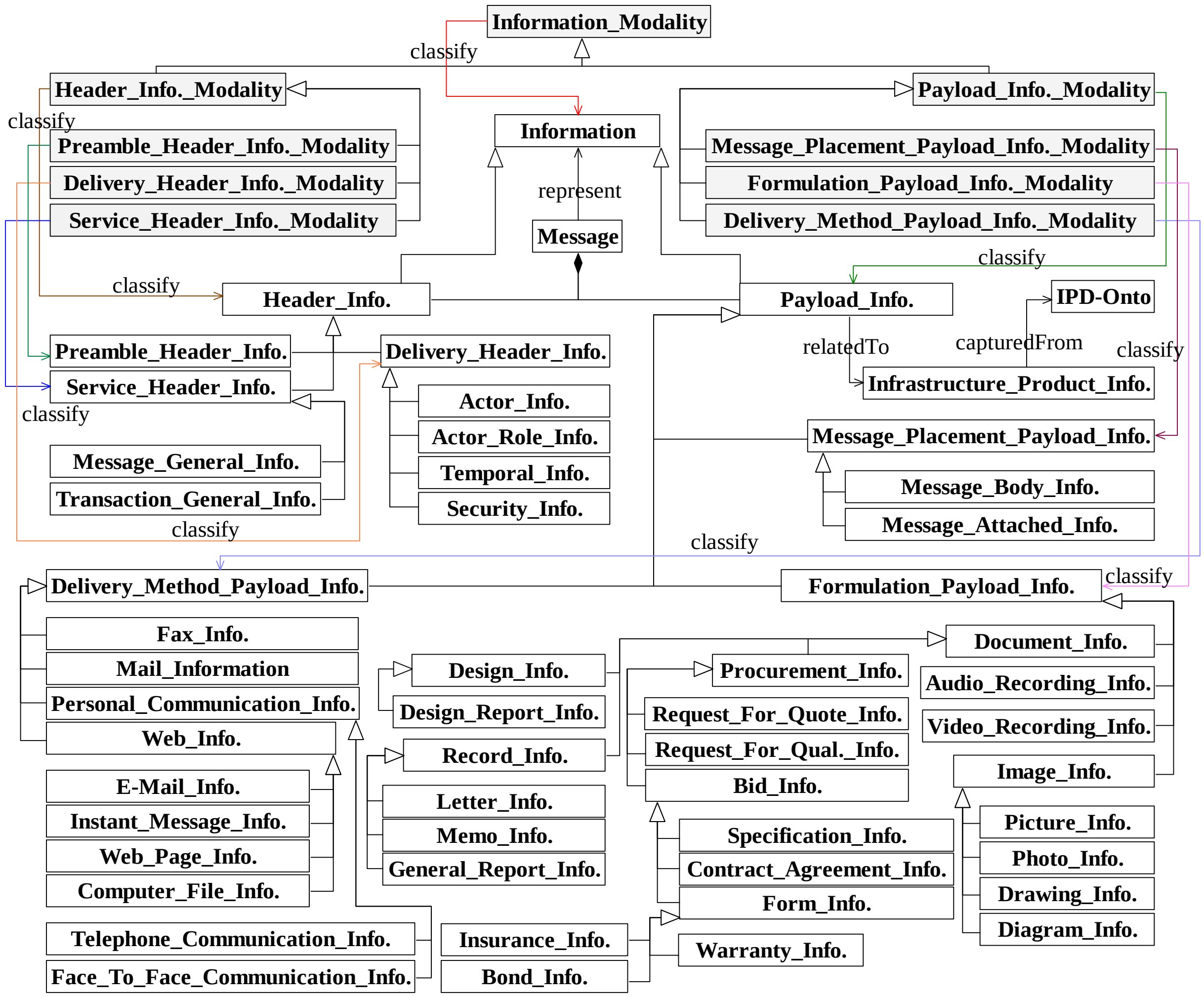

Figure E-4 Taxonomy of information

E.1.6.2.1 Header Information Modality

The header information modality classifies message header information that is represented in a message template (MT). According to RosettaNet (2002), the header information is of three types: preamble, delivery and service header information. Therefore, header information is classified according to the following three modalities: preamble, delivery, and service header information modality.

Preamble header information modality—classifies header information that is related to the version of the underlying data model or the message template. It is a mandatory header and is never encrypted.

Delivery header information modality—classifies header information that is related to the actor, actor role, temporal (time-related, e.g. duration of the transaction, message sent date, message read date, etc.), and security (i.e. high, medium, and low security) information. It is a mandatory header and is never encrypted.

Service header information modality—classifies header information based on the general information related to the transaction and message, e.g. name, purpose, description of the transaction and message. It is a mandatory header that may be encrypted.

E.1.6.2.2 Payload Information Modality

The payload information modality classifies message payload information based on the way that: (i) information is placed in a message; (ii) information is created or formulated; and (iii) information is delivered to other parties. It has the following three sub-classes.

Message placement payload information modality—classifies information based on the way it is placed in a message template and communicated between the parties. Based on placement, the information is of two types: message face/body information (represented in the body of the message) and message attached information (represented as an attachment to the message).

Formulation payload information modality—categorizes information based on the way it is created or formulated, e.g. document, audio recording, video recording, and image information. The document information is classified as procurement information, design information, and record information that are categorized as shown in Figure E-4.

Delivery method payload information modality—classifies information based on the media or channel through which information is exchanged between the collaboration partners in a given transaction. It has four sub-classes: fax information, mail information, personal communication information (e.g. telephone and face-to-face communication information), and web information (e.g. E-mail, instant message, web page, and computer file information). For the design and implementation of MTs in the domain of infrastructure, payload information related to infrastructure products or tangible capital assets (TCAs) can be captured from the IPD-Onto or TCA_Onto.

E.1.6.3 Attribute Taxonomy—Support Concept

According to Osman (2007), an attribute is a characteristic, feature, or property that describes a thing, entity, or concept. The taxonomy of attributes in the Trans_Dom_Onto was developed for the following two concepts: transaction and information, message, actor/actor role attribute. A set of transaction attributes is represented in Figure E-5.

E.1.6.3.1 Transaction Attributes

Transaction function attribute—is a characteristic that describes a transaction based upon the function it performs in a given communication. In a given transaction, a function can be to disseminate information or request the receiver to perform an action.

Transaction dependency attribute—is a characteristic that describes a transaction based on the logical, geographic, and cyber dependency. Dependencies govern the design and implementation of transactions in practical scenarios. *Logical dependency attribute*—describes the sequence through which a bi-lateral or multi-lateral transaction is completed. To accomplish a transaction successfully, atomic transactions are to be performed in sequence. *Geographic dependency* *attribute*—describes the geographic context of a transaction. It is important because changing the geographic context requires modifying the standard transaction agreement/transaction specifications to suit the local conditions. Geographic context forms the basis and governs the design of a transaction. *Cyber dependency attribute*—describes the cyber requirements of a transaction. Semi-automated computer-to-computer transactions require internet based automated systems (cyber) for the exchange of information.

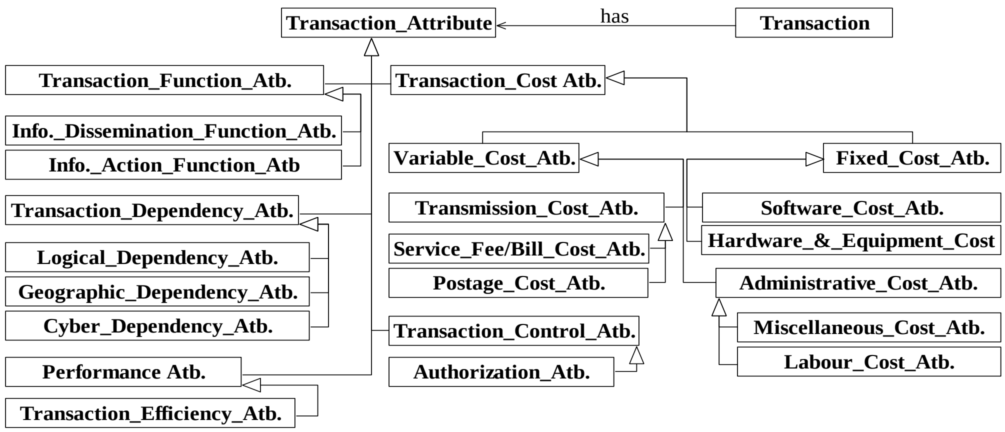

Figure E-5 Taxonomy of transaction attributes

Transaction performance attribute—is a property that describes the performance of a transaction in terms of its transaction efficiency. A transaction is efficient if its performance is excellent in terms of time, cost, and quality.

Transaction cost attribute—is a property that describes the transaction design, implementation, and operational cost. According to Fabozzi *et al.* (2005), transaction cost has two types: fixed cost and variable cost. *Fixed cost*—is a one-time cost incurred upfront on designing and implementing a transaction system. It has two types: software and hardware and equipment cost. *Variable cost*—describes the transaction operational cost related to administration and transmission of transactions. This cost varies with time and has two sub-classes: administrative and transmission costs.

Transaction control attribute—is a characteristic that describes the transaction security in terms of transaction authorization.

E.1.6.3.2 Information, Message, and Actor/Actor Role Attributes

The attributes of the message and actor role concepts are captured in terms of the information attribute; therefore, all the three types of attributes are merged together and are represented in the Figure E-6.

The classification of information attributes is based on header information and payload information with former has header information attribute and later has payload information attribute as defined below.

- Header Information Attribute

  The header information attributes describe the characteristics of the message header information. It has three sub-classes: preamble, delivery, and service header information attribute.

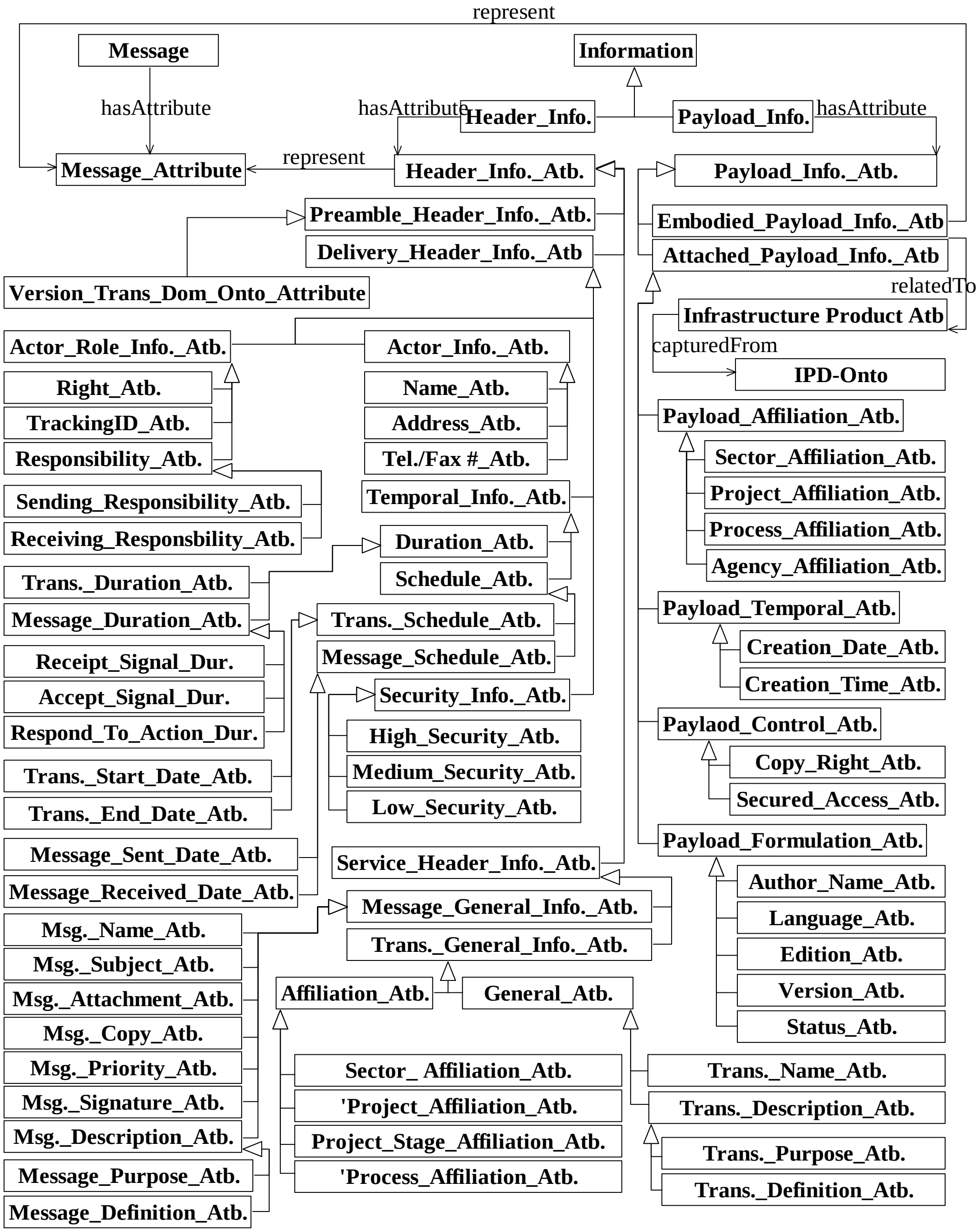

Figure E-6 Taxonomy of information, message, and actor/actor role attributes

Preamble header information attribute—describes the characteristics of the preamble header information in terms of the version of the Trans_Dom_Onto based on which message templates are designed.

Delivery header information attribute—describe the characteristics of the message header information in terms of the actor, actor role, temporal, and security attributes.

- Actor and actor role information attribute—are the characteristics that describe actor and actor role header information. The *actor information attributes* includes the name, address, and telephone/Fax number of the actor. The *actor role information attributes* include rights, responsibilities (Zhang, 2007), and tracking ID of the actor role in a given transaction. The responsibilities of an actor role in a given transaction are sending and receiving the message containing the required information. Therefore, responsibility attribute is categorized into sending and receiving responsibility attributes.

- Temporal information attribute—describes time related attributes of the header information. It has two sub-classes: duration and schedule attributes. The *duration attribute* is the time span in which a message or transaction is accomplished successfully. It has two types: transaction duration and message duration. The *transaction duration* represents the combined duration of all atomic transactions in a bi-lateral and multi-lateral transactions. The *message duration* represents the period in which a single message is transmitted between the parties successfully. The message duration has three types: receipt signal, accept signal, and respond to action duration attributes. *Receipt signal duration attribute* represents the time required to send a receipt signal in response to an action message. *Accept signal duration attribute* represents the time required to send an accept signal in response to an action message in a two action design pattern transaction. *Respond to action duration attribute* represents the time required to successfully transmit a response action message by the receiver to the sender role. Moreover, the *schedule attribute* refers to the time at which a transaction or message commences, dispatches or terminates. It has two sub-classes: transaction schedule and message schedule attributes. *Transaction schedule* describes the start and end date of the transaction, whereas message schedule represents the message sent and received date.

- The security information attribute—describe the characteristics of the delivery header information in terms of secured transport of the information. It includes transporting messages with high, medium, and low security requirements.

Service header information attribute—describes the characteristics of the message and transaction general information.

- The message general information attribute—describes the characteristics of the service header information that relates to a specific message. It has the following sub-classes: message name, message subject, message attachment, message copy, message body, message priority, message signature, and message description. The *message description* represents the purpose and definition of the message.

- The transaction general information attribute—describe the characteristics of the service header information pertaining to the transaction. It has two sub-classes: general and affiliation attributes. The general attributes represent the name and description of the transaction. The *transaction name* refers to the specific name of a transaction whereas the transaction description represents the definition and purpose of the transaction. Moreover, the transaction *affiliation attributes* focus on the relationship or belonging of the transaction to a specific infrastructure sector, project, project stage, and process.

- Payload Information Attribute

Payload information attribute—describes characteristics of the payload information. It is classified as embodied or attached payload information attribute depending on whether it is embodied (in a message) or attached (to a message) information. The embodied payload and header information attributes represent message attributes, which is represented in terms of information attributes and a separate message attribute taxonomy is not developed.

Embodied payload information attribute—describes characteristics of the payload information represented in the body of the message template. These attributes are represented in the Infrastructure Product Ontology (IPD-Onto) (Osman, 2007) and Tangible Capital Asset Ontology (TCA_Onto) developed as part of this research work. If required for the design of message templates, the attributes related to the infrastructure products or tangible capital assets (e.g. pipe, valve, chamber, cable, road, and so on) can be captured from these two ontologies. Due to which a link between the Trans_Dom_Onto and IPD-Onto is established.

Attached payload information attribute—describe characteristics of the payload information that is attached to a message template and is referred to as knowledge or information item. According to Zhang (2007), a knowledge item (attached payload information) has the following attributes that are re-classified in the Trans_Dom_Onto.

- Payload affiliation attribute—describes the relationship, connection, or belonging of the attached payload information to a sector, project, process, or agency. It has the following four classes: sector affiliation, project affiliation, process affiliation, and agency affiliation.
- Payload temporal attribute—is a meta attribute representing time-related characteristics of the attached payload information. It has two types: creation date and time attribute that represents the date and time at which an information item is created.
- Payload control attribute—is a meta attribute describing the authority and ownership of individual(s) or organization(s) on the use or access to the attached payload information item. It has two sub-classes: copyright and secured access attributes. These attributes describe that who has the copyright and who is authorized to access the attached payload information item.
- Payload formulation attribute—represents the meta information about the payload information. It has five classes: author name, language, edition, version, and status (draft or final) of the payload information item.

E.1.6.4 Mechanism Taxonomy—Support Concept

The mechanism represents the tools and means required to accomplish a process or transaction successfully (El-Gohary *et al.* 2006). The mechanism is an abstract concept that is categorized into six sub-classes: theoretical foundation, abstract concept, parameter, attribute, technique, and measure (El-Diraby, 2005). According to El-Gohary (2008) and Osman (2007), the mechanism is an umbrella concept that has three sub-classes: guide, method, and measure. As part of the Trans_Dom_Onto, the taxonomy of mechanism was developed based on these three concepts as shown in Figure E-7.

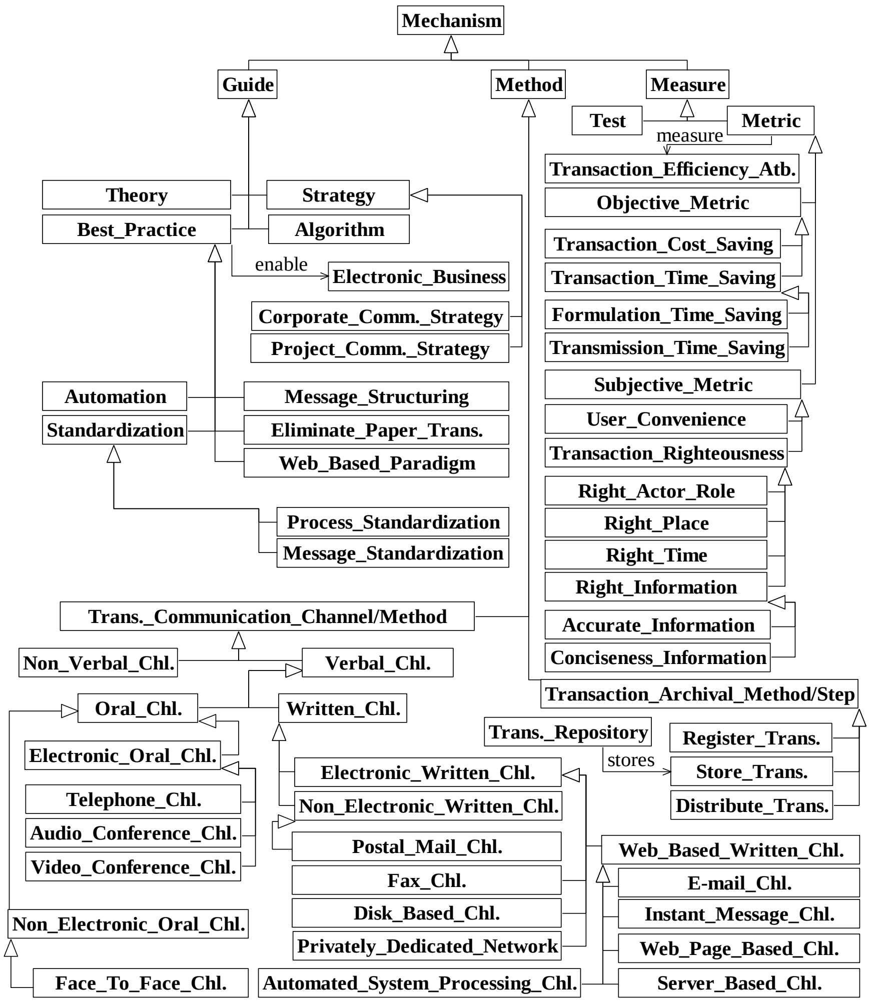

Figure E-7 Taxonomy of transaction mechanisms

E.1.6.4.1 Guide

The guide is a basic information or instructions needed to support the work of actor role in all work processes and communications. It has the following four sub-classes.

Theory—is the accepted body of knowledge developed through testing, experimentation, and conceptual research to represent some aspects of the real world. In the Trans_Dom_Onto, theory relates to a well-defined transaction formalism protocol specification that the transaction development personnel will use to create standard transaction agreements/transaction specifications in the area of infrastructure management.

Best practices—refers to the most effective, efficient, and innovative ways used to accomplish an objective. It improves organizational efficiency through achieving optimum results. Some of the best practices are represented in the Trans_Dom_Onto that would facilitate electronic business in the AEC/FM industry.

- Automation—is to minimize human handing of transactions. It is a good practice to implement fully or semi-automated transactions in the AEC/FM industry. In a fully automated transaction, the computer automatically generates and transmits the message to receiving system, whereas in semi-automated transaction, computer generates and transmits the message to the receiving system with the aid of a human/individual. As a first step, confirmation acknowledgment transactions can be implemented as a fully automated transaction.

- Standardization—transactions and messages standardization has several advantages: (i) quick team building as all aspects of a communication is already defined; (ii) eases creation of communication agreements between the partners; (iii) consistent exchange of information improves transaction efficiency in terms of reduced transaction formulation time, enhanced user convenience, enhanced transaction righteousness (accurate and concise information); (iv) eases implementation into computer based solutions as transaction specifications are already defined; and (v) achieve message-based interoperability between information systems of collaboration partners in the AEC/FM industry. Keeping in view the advantages, it is a good practice to standardize transactions (the communication process) and messages that are exchanged between the collaboration partners in a given transaction using computer based systems.

- Message structuring—structured exchange of information through predefined templates (structured messages) has the advantages of time saving in message formulation, reduce errors as information is already defined and represented in the message template, and reduce information redundancy as only required information is reflected in the message template. A well-defined and well-structured exchange of information between the collaboration partners improves transaction efficiency as well as eases implementation of the electronic business (computer-to-computer) in the AEC/FM industry.

- Eliminate paper transaction/manual transaction—presently, communications in the AEC/FM industry are manual and performed on ad-hoc basis. In order to enable or facilitate electronic business (i.e. fully automated or semi-automated computer-to-computer transaction) in the AEC/FM industry, these manual transactions specifically the paper-based transactions need to be eliminated. This would rectify the issues associated with the paper based transactions, including; difficulty in tracking transactions, increased storage space requirements for transaction records, high transaction record retrieval time, and prone to errors due to human intervention.

- Web-based paradigm—for efficient and cost effective exchange of information between the collaboration partners in the AEC/FM industry, it is important to transform to web-based paradigm using state-of-the-art information technologies. It allows the actor roles to exchange information synchronously as well as asynchronously between geographically scattered AEC/FM teams. The built-in support for interactive capabilities in web-based systems further enhances communication effectiveness. The web based systems provide transaction record archival services that reduce the transaction record storage space requirement as well as assist in quick searching and retrieval of the records.

Strategy—is defined as an idea, design, or layout to achieve a particular goal with flexibility to change and open to adaptation. Two types of strategies are represented in the Trans_Dom_Onto. The *corporate communication strategy* relates to the inter/intra-organizational communication that are independent of a specific project context, whereas the *project communication strategy* pertains to project level communications. These strategies guide the design and implementation of the communication systems required for improved delivery of services.

Algorithm—is a step-wise procedure developed to solve problems that can be used for implementation of the Asset Information Integrator System, which is developed as part of this research work.

E.1.6.4.2 Method

The method is a generic concept that covers all such means, mediums, and techniques used to exchange and store transactions. In the Trans_Dom_Onto, methods for transaction transmission and transaction archiving are represented.

Transaction communication channel/method—is defined as the medium through which information is transmitted between the transaction roles (sender and receiver role). The choice to select a specific transaction type (e.g. web-based transaction, fax transaction, telephone transaction, etc.) between partners in the AEC/FM industry is highly dependent on the type and availability of the communication channel. According to Esposito *et al.* (2007), communication channel has two abstract sub-classes: non-verbal and verbal channel. The *non-verbal channel* is a mode of communication that enables the exchange of information between the parties without the use of words (e.g. gesture, body language, eye contact, posture, touch, etc.). This channel is beyond the scope of this research work. The *verbal channel* is a mode of communication that enables exchange of information between the parties using words. It has two sub-classes: written and oral channel.

- The written channel is a mode of communication that enables exchange of information between the parties using written words. It is further classified into electronic and non-electronic written channels. The electronic written channel is a mode of communication that is used to transmit information between the partners using some sort of technology, "electrical, digital, magnetic, wireless, optical, electromagnetic, or similar capabilities" (BC-Reg, 2001 and NCC-USL, 1999). It is further classified into four main sub-classes: web (E-mail, instant message, web page, server-based, and automated system processing), fax, disk-based, and privately dedicated network channels. Moreover, the *non-electronic written channel* is a mode of communication that is used to transmit information between the roles without the use of any technology. In other words, transactions are taking place between the roles using physical means, e.g. postal mail channel.
- The oral channel is a mode of communication that enables exchange of information between the parties using spoken words. It has two types: electronic and non-electronic oral channels. The *electronic oral channel* is a mode of communication that enable the exchange of information between the parties through spoken words using some sort of technology (e.g. electrical, digital, wireless, optical, etc.). It has three sub-classes: telephone, audio conferencing, and video conferencing. The *non-electronic oral channel* is a mode of communication that is used to exchange spoken information between the collaborating roles without the use of any technology, e.g. face-to-face communication.

Transaction archival method—represent the steps to archive standard transaction agreements/transaction specifications in a web-based centralized location—Infrastructure Transaction Management Portal. In the Trans_Dom_Onto, *archiving* is the process of storing transaction specifications in the web portal in a way to make it accessible in a controlled manner. According to COINS (2009), archiving is done in three steps. *Register transaction* refers to recording and registering the status of the standard transaction agreements/transaction specifications. *Store transaction* refers to storing the transaction specifications along with its registration information in a web based transaction repository - the Infrastructure Transaction Management Portal. *Distribute transaction* refers to distribute copies of the latest version of the transaction specifications to all authorized roles.

E.1.6.4.3 Measure

According to Osman (2007), the measure is an abstract concept used to gauge conformance of an entity's attribute to a pre-defined requirement as prescribed by specifications and codes. It has two types: test and metric depending on whether the entity is concrete or abstract. The test is used to measure conformance of the characteristics of a physical entity/concrete concept to the desired specification and code requirements. For instance, conducting a tensile strength test to measure the tensile strength (steel strength attribute) of steel (physical entity/concrete concept). The metric refers to the criteria used to gauge the conformance of the attribute of an abstract entity with respect to predefined requirements. The metric for the transaction (abstract entity) efficiency (attribute) is represented in the Trans_Dom_Onto, which has two sub-classes: objective metric and subjective metric.

Objective metric—captures quantitative measurement of the transaction efficiency. It has two sub-classes: transaction cost savings and transaction time savings. The *transaction cost saving* metric measures the savings in the cost due to implementation of the computer-to-computer based communication systems, whereas the *transaction time saving* measures the savings in time due to implementation of computer based communication systems. The transaction time saving is measured in terms of formulation and transmission time saving. The *formulation time saving* refers to the time transaction roles save in formulating or composing or creating a message/transaction instance. In template-based exchange of information, formulation time includes the search time for the message template over the web, download time, and data fields filling time. The *transmission time saving* refers to the time, actor roles save, while transmitting messages from the sender to the receiver role. The transmission time starts when a sender role transmits the message and terminates when the receiving party receives the message. Both the time savings are calculated using a comparative analysis with other modes of communications.

Subjective metric—captures qualitative measurement of the transaction efficiency. The quality of a transaction is measured in terms of user convenience (Zott *et al.* 2000) and transaction righteousness. The *user convenience* is achieved through easing; (i) understandability of the message content; (ii) handling and processing of transactions; and (iv) transaction approval process prior to transmission. The *transaction righteousness* measure the quality of a transaction based on 4R factors: right actor role, right time, right place, and right information. A transaction (atomic transaction or message) is said to be efficient and effective, if it is directed to the *right role* at the *right place* at the *right time* with the *right information*. Any discrepancy in the 4R would result in significant communication inefficiencies. The *information righteousness or right information* is measured in terms of accurate information and concise information. The *accuracy* measures conformance of the information represented in the message with the actual required information, (e.g. 3 inches instead of 3 feet). The *conciseness* measures conformance of the information with the user requirements in a given transaction in terms of the redundancies.

E.1.6.5 Transaction Constraint—Support Concept

The transaction is controlled by a set of constraints. The transaction *constraints* refer to the conditions, factors, requirements, and obligations that restrict the way transactions are to be designed, managed, and implemented in the domain of infrastructure management. It has the following two abstract sub-classes: internal and external constraint as shown in Figure E-8.

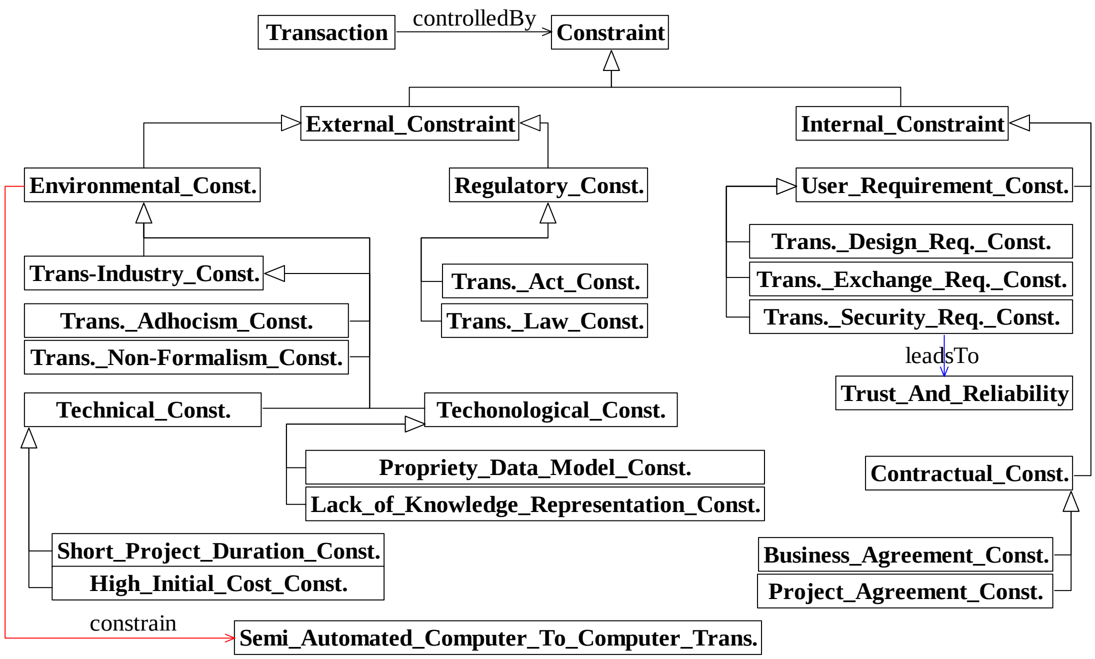

Figure E-8 Taxonomy of transaction constraints

E.1.6.5.1 Internal Constraint

The internal constraint refers to the requirements and obligations of the collaboration partners in a given transaction. It has two sub-classes: user requirement and contractual constraints.

User requirements constraint—covers transaction design and implementation requirements of the collaboration partners. The user requirements include the transaction design requirement, transaction exchange requirement, and transaction security requirements. The *transaction design requirements* focus on the way actor roles want to design a transaction. For instance, actor roles may opt to design a transaction using a one-action with/without acknowledgment *vs.* two-action with/without acknowledgement design pattern, or synchronous *vs.* asynchronous transactions, etc. The *transaction exchange requirements* represent the information that the users need to exchange in a given transaction. These requirements control the design of message templates that are exchanged in specific transaction (i.e. what needs to be incorporated in the message template and how to represent it). The *transaction security requirements* focus on the way actor roles want to incorporate security features in the design and implementation of transactions. The security features ensure information reliability that leads to develop trust amongst collaboration partners.

Contractual constraint—refers to the obligations of the actor roles under contract stipulation/agreement that governs the design and implementation of a transaction. It has two types. The *business agreement* is the general agreement between the collaboration partners that translates how the business is to be carried out. The *project agreement* is the agreement between the collaboration partners on how to accomplish a specific project. Both of these agreements clearly spells out the way communication is to be carried out to complete activities in the business and project levels. Both the agreements, capture transaction requirements, e.g. what channel is to be used for communication, who will be the sending and receiving parties in a communication, and what information is required to be exchanged in a given communication. All of these requirements govern the design and implementation of transactions in the domain of infrastructure management.

E.1.6.5.2 External Constraint

The external constraint covers all those constraints that are beyond the control of the collaboration partners. It has two sub-classes: regulatory and environmental constraints.

Regulatory constraint—encompasses all acts and laws that regulate the design, implementation, and management of transactions. It is classified as transaction law and transaction act. The *transaction act* and *transaction law* regulates the design, implementation, and management of transactions in terms of the requirements stipulated in the act.

Environmental constraint—constrains the design, implementation, and management of electronic transactions with specific focus on semi-automated computer-to-computer transaction in the AEC/FM industry. It has three sub-classes: trans-industry, technical and technological constraints.

- The trans-industry constraints represent current transaction practices across the AEC/FM industry. It has two sub-classes: transaction ad hocism and non-formalism. The *transaction ad hocism constraint* is the situation specific definition of transactions that are defined, documented, and standardized as required for computer-to-computer based exchange of information. The *transaction non-formalism constraint* refers to the current practice of information exchange in the AEC/FM industry wherein transactions and messages are not well-defined and accomplished in an unstructured way. The non-formalism of transactions and messages is the main barrier to the design, implementation, and management of electronic communications in the construction industry. According to Zeb *et al.* (2013), the transactions are not defined presently, and conducted on an adhoc basis in the domain of infrastructure management. For computer-to-computer based exchange of information, these transactions and messages need to be defined and structured.
- The technical constraint is classified as short project duration and high initial cost of communication system development. These constraints hamper implementation of computer-to-computer transactions, specifically in small to medium level AEC/FM organizations.
- The technological constraint hampers the design and implementation of computer-to-computer transactions in the AEC/FM industry. These constraints are: propriety data models and lack of knowledge representation in the domain of infrastructure management. *Propriety data model constraint*—infrastructure agency have developed their own propriety data models to manage their infrastructure systems. Due to the heterogeneous

nature of these models, message level formalization is likely impossible, which is a prerequisite for computer-to-computer (C2C) based exchange of information. *Lack of knowledge representation constraint (the ontology)*—lack of knowledge representation also hampers the design and implementation of C2C transactions in the infrastructure management segment of the AEC/FM industry. For C2C transactions, messages are to be defined in a neutral format—the ontology, to achieve message based interoperability between information systems of the infrastructure organizations.

E.1.6.6 Relationship Taxonomy—Support Concept

The relationships represent the associations between diversified concepts in an information model or knowledge base and is termed as properties in the ontology web language. In the Trans_Dom_Onto, relationships were grouped into two types: hierarchal and directed association relationships as shown in Figure E-9.

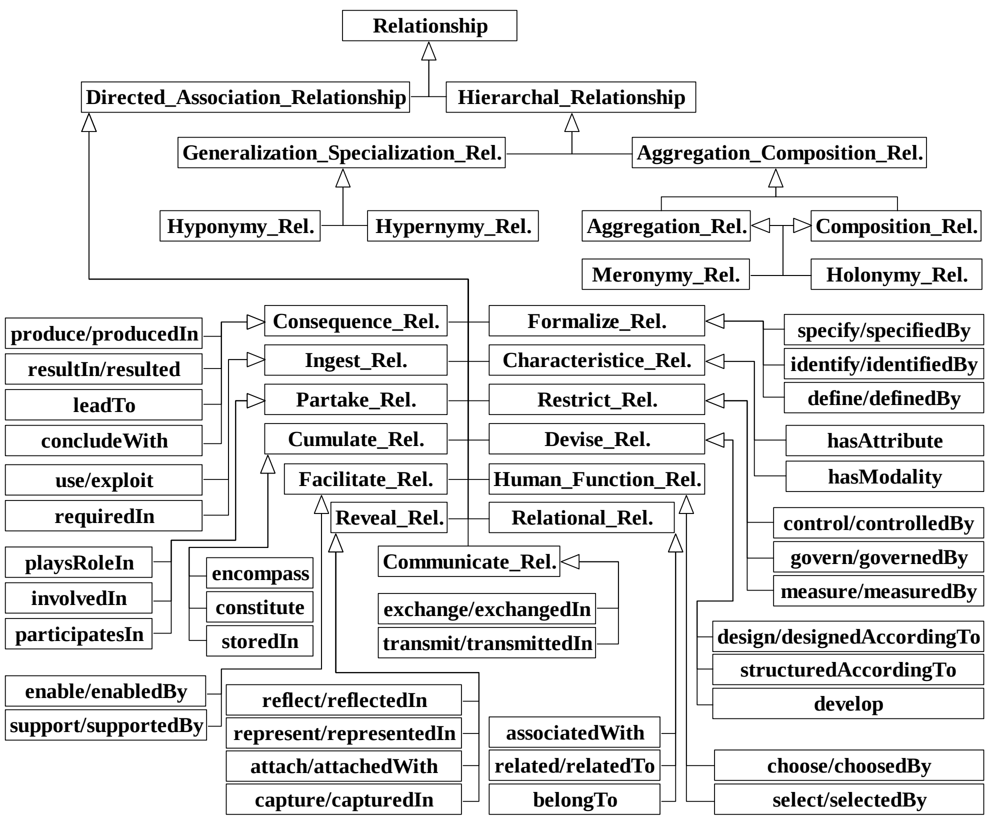

Figure E-9 Taxonomy of relationships

E.1.6.6.1 Hierarchal Relationship

The hierarchal relationships include the generalization-specialization and aggregation-composition relationships.

Generalization-specialization relationships—represent "is-a" or "type-of" or "parent-child" relationship between concepts. It associates top-level generic concepts with the lower level specific concepts. According to El-Gohary (2008), it has two types: hyponymy and hypernymy. The hyponymy represents the relationship of the sub-class with its super-class, whereas the hepernymy represents the relationship of the super-class with its sub-class in a generalization-specialization relationship.

Aggregation-composition relationships—are whole-part relationships that represent the relationship between the whole and its parts, which is also known as "partonymy" (El-Gohary, 2008). It has two sub-classes: aggregation and composition relationship. The core difference between the two is the existence of the "part" in case the "whole" concept is no more existing. In aggregation relationships, "part" concept exists even "whole" concept is no more existing, wherein composition relationships "part" concept vanishes when the whole concept is no more existing. For instance, the relationship between the message (whole concept) and header information and payload information (part concepts) is shown in Figure E-10, representing a composition relationship because the header and payload information will not exist if there is no message. According to El-Gohary (2008), both the aggregation and composition are further classified as meronymy and holonymy. For example, as shown in Figure E-10, the relationship between the payload information (part) and the message (whole) is referred to as meronymy, whereas the relationship between the message (whole) and the header information (part) is termed as holonymy.

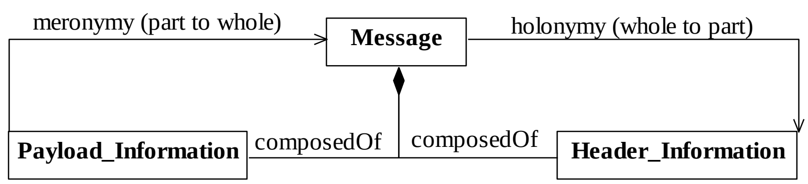

Figure E-10 Whole-part composition relationship—(partonymy)

E.1.6.6.2 Directed Association Relationship

The association or directed association represents other than "is-a" or "part-of" relationships in a knowledge representation. The directed associated relationship represents cross concept associations in the Trans_Dom_Onto. The purpose of the directed association relationships is to enrich the knowledge representation. The directed association relationship represented in the Trans_Dom_Onto has the following 13 abstract sub-classes. These relationships or properties were used to explicitly describe the concepts in the Protégé ontology editor in terms of the property restrictions that is discussed later in Section E.1.7.

- The formalize relationship was used to describe concepts in terms of its specification and definition. For example, specify/specifiedIn, identify/identifiedBy, and define/definedBy, etc.
- The characteristic relationship was used to identify key characteristics of the transaction concepts. For example hasAttribute, hasModality, describecostCharacteristicOf, etc.
- The restrict relationship was used to represent a restraint while describing transaction concepts in the Trans_Dom_Onto. For example, control/controlledBy, govern/governedBy, and measure/measureBy, etc.
- The devise relationship was used to describe the way a concept is formulated or created. For instance, design/designedAccordingTo, structuredAccordingTo, develop, classify, etc.
- The human function relationship was used to represent the key functions that an actor role plays in a bilateral or multilateral collaboration. For instance, choose/choosedBy, select/selectedBy, conductedIn, etc.

- The relational relationship was used to specify belonging or relatedness of a concept with others concepts. For example, associate/associatedWith, related/relatedTo, belong/belongTo, etc.
- The communicate relationship was used to describe perspectives related to transaction communication. For instance, exchange, transmit/transmittedIn, send, receive, etc.
- The reveal relationship was used to describe revelation aspect of a concept, i.e. what a transaction concept reflects or represents in a given context. For example, reflect/reflectedIn, represent/representedIn, attach/attachedWith, capture/capturedIn, etc.
- The facilitate relationship was used to represent facilitation between different transaction concepts, i.e how a concept supports or enables another concept in the ontology. For example, enable/enabledBy, support/supportedBy, etc.
- The cumulate relationship was used to scope the coverage of a concept or identify amassing of transaction concepts. For instance, encompass, constitute, storedIn, groupedIn, within, include, etc.
- The partake relationship was used to describe participation of the actor role in a transaction. For example, play/ playRoleIn, involve/involvedIn, participate/participateIn, etc.
- The ingest relationship was used to describe the usage or requirement of a transaction concept. For example, use/exploit, require/requiredIn, etc.
- The consequence relationship was used to describe an outcome. For example, produde/producedIn, resultIn/resulted, leadTo, concludeWith.

E.1.7 Step 7—Capture Ontology

The capture ontology means unambiguous declarations of the concepts represented in the ontology, which is named as axioms. According to (Osman, 2007 and El-Gohary 2008), axiom unambiguously defines the concept represented in the ontology and constraint on it's interpretation. According to Gruninger and Fox (1995), axiom specifies unambiguous definitions of the concepts in a specific domain. In the Trans_Dom_Onto, axioms were used to explicitly define the classes of concepts as per classification shown in Figure E-11.

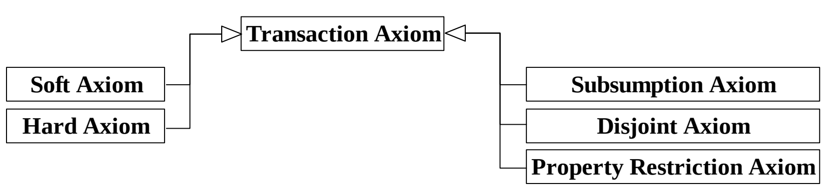

Figure E-11 Taxonomy of axioms

E.1.7.1 Soft and Hard Axiom

The transaction axioms were classified as soft axiom and hard axiom. The *soft axiom* refers to the definition of the concepts in plain English Language, whereas the *hard axiom* specifies the definition of the concepts using the Ontology Web Language (OWL) based Description Logic Syntax (DL). The soft axioms of the Trans_Dom_Onto were captured as part of the description of the core and support concept taxonomies developed in Step 6 (extend Trans_Dom_Kernel_Onto).

E.1.7.2 Subsumption Axiom

In the *subsumption axiom*, classes were explicitly defined in hierarchies with parent-child relationship, where a child class inherits properties from the parent class and is subsumed by the super-class. In the OWL formal language, it is written as “Individual Sub-classOf Actor”, where “individual” is a sub-class and “actor” is a super-class.

E.1.7.3 Disjoint Axiom

In the *disjoint axiom*, classes were explicitly described to be disjointed from each other, which mean an individual as a member of class “x” cannot be an instance of another class. For example, the two sub-classes of the actor super-class are: individual and organization, which needs to be defined as disjointed, so that an instance of individual sub-class, “Hudson” cannot be a member of the organization sub-class (municipality). In OWL formal language, it is written as “Individual disjointWith Organization”.

E.1.7.4 Property Restriction Axiom

According to Horridge (2009), *properties* describe the binary relationship between the concepts, whereas the *datatype properties* describe the relationships between the individuals and data values, where individuals in OWL represent the instances of a class. In OWL, classes are defined in terms of the property restrictions, which states that “a restriction describes a class of individuals based on the relationships that members of the class participate in” (Horrdige, 2009), and therefore, a property restriction represents a class of individuals. The property restrictions are of three types.

E.1.7.4.1 Quantifier Restriction

The *quantifier restriction* describes the restriction in terms of quantifying the relationship or property. In the OWL, the quantifier restriction is a combination of three elements: the anonymous class of things, property, and filler as shown in Figure E-12. The anonymous class of things defines a class of things (i.e. actor), play is the property that is restricted in the given context, and the filler represents a specific class of individuals (i.e. design engineer role or project management role). As per the diagram, the anonymous class of things is related to the individuals of the filler class through the restricted property “play”. In other word, these are the class of individuals that participate in some play relationship with other individuals. In this way, the classes are described and defined in terms of the relationships that these individuals participate in, as such, the class description is restricted to the relationships. The quantifier restriction has two types: existential restriction and universal restriction.

Existential restriction—describes a class of individuals (anonymous class of things) that participate in at least one kind of relationship along a specified property (play) to individuals that are members of a specified class (design engineer role). The example in the Figure E-12 also illustrates that individuals in the anonymous class of things (actors) may also have relationship along the same property (play) to individuals that are members of another class (project management role). This shows that the restriction does not constrain the “play” relationship to individuals that are members of a specific class “design engineer role”, but it can also be related to individuals that are members of the other class “project management role”, along the same property “play”. In other words, existential restriction focuses on the existence of “some” or “at least one” relationship along a specific property to individuals that are members of a specific class. The existential restriction is also known as "someValueFrom restriction", and "Some restriction", denoted by "∃" in the Description Logic Syntax (DL). The existential restriction captured in Figure E-12 can be written as "∃ play Design_Engineer_Role" in the formal OWL Description Logic Syntax or "play some Design_Engineer_Role". In simple English, it means that "actor" is a class of individuals that play some or at least one role that is design engineer role. The restrictions describe the necessary conditions for individuals to be members of a class of things. For individuals to be members of a class of things is supposed to fulfill these necessary conditions. In OWL, these necessary conditions are known as the super-classes and the classes of things that satisfy these conditions are said to be the primitive classes. For an individual to be a member of a class, then it is necessary to fulfill the necessary conditions, but it cannot be said that any random individual that satisfy these necessary conditions must be a member of that specific class. For any random individual to be a member of this class, there is a need to describe necessary and sufficient conditions in order to establish that these conditions are not only necessary for the membership, but also sufficient to determine that any random individual that satisfies them must be a member of that specific class. In the OWL, necessary and sufficient conditions are known as "equivalent classes" and the class of individuals satisfying necessary and sufficient conditions is termed as "defined classes".

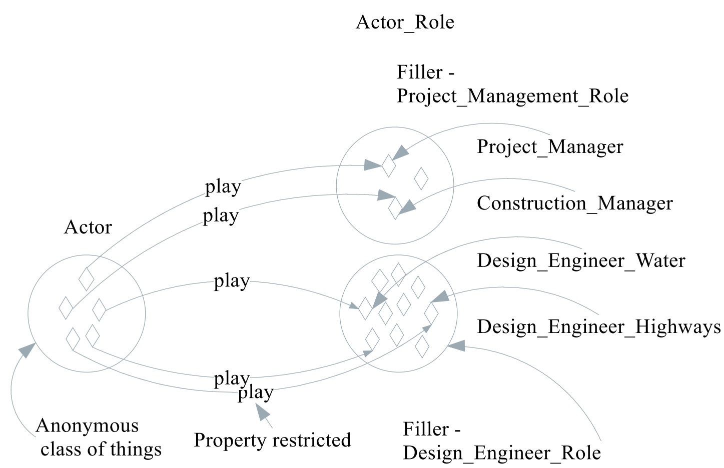

Figure E-12 Existential restriction

Universal restriction—is also knows as "allValueFrom restriction". The universal restriction describes a class using three elements: the property that is restricted, the type of restriction "only" or "∀" and the filler. An example of the universal restriction is presented in Figure E-13, which is written as "play only Design_Engineer_Role" and in the OWL Description Logic Syntax as "∀ play Design_Engineer_Role". In this example, "play" is the property restricted, "only" is the type of restriction, and "design engineer role" is the filler. In this restriction, filler class is also restricted for a given relationship. The universal restriction in the example describes a class of individuals (anonymous class) that for a given property "play" only have relationships to individuals that are members of a specific class, i.e. design engineer role. In other words, it describes a class of individuals that doesn't participate along the same property "play" to individuals that are members of another class, i.e. project management role. The universal restriction doesn't capture existence of a relationship along a given property between the individuals of anonymous class of things and the specified filler class states, if a relationship exists, then it must be with an individual that is members of the specified filler class, i.e. design engineer role. This discussion emphasizes to use universal restriction jointly with existential restriction, as the latter guarantees existence of a relationship and the former takes care of the "only" relationship.

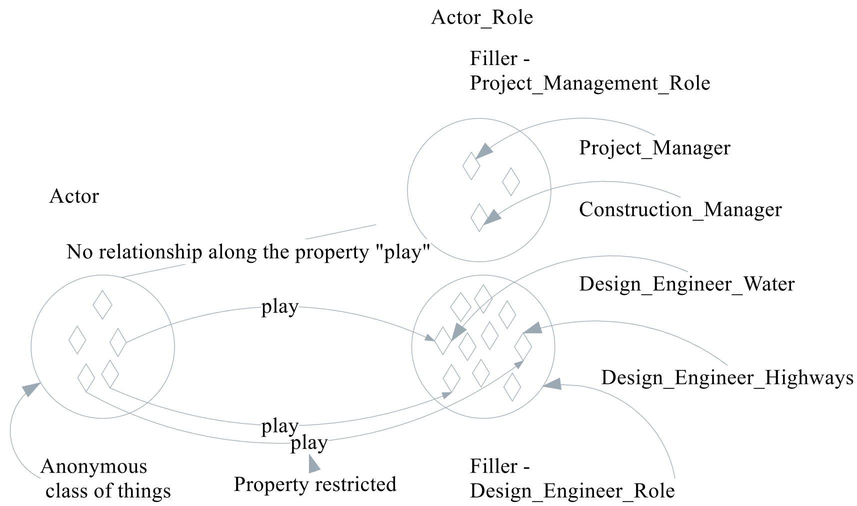

Figure E-13 Universal restriction

E.1.7.4.2 Cardinality Restriction

In the OWL, an anonymous class of things can be described in terms of the number of relationships that an individual of the anonymous class of things participates in, along a specific property to other individuals or datatype values. A class description in term of the number of relationships is known as cardinality restriction. A cardinality restriction" is said to be qualified cardinality restriction when a specific class of objects is stated within the restriction. An example of the cardinality restriction is captured in Figure E-14. In the OWL, cardinality restrictions are of three types: minimum cardinality restriction, maximum cardinality restriction and exact or cardinality restriction.

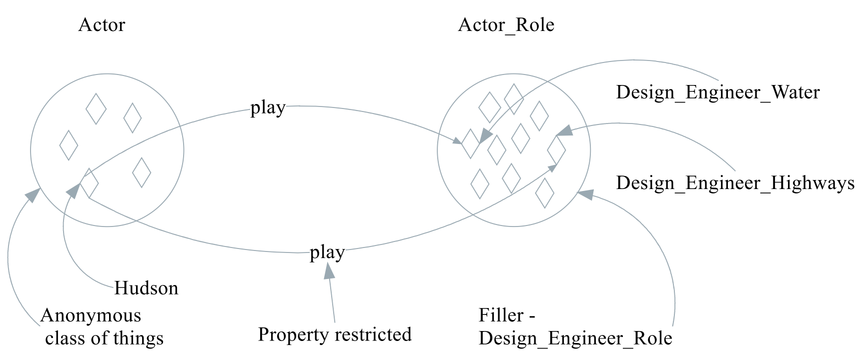

Figure E-14 Cardinality restriction

Minimum cardinality restriction—describes an anonymous class of things in terms of the minimum number of relationships that an individual of the anonymous class must participate in, along a specific property. It is denoted by "≥" in the Description Logic (DL) Syntax. From the example in Figure E-14, Hudson an individual, who participate in a minimum of two relationships with two different design engineer role, (i.e. design engineer highways and design engineer water) along the same property "play". The minimum cardinality restriction describes a class of things in the formal DL Syntax as "≥ playRole 2", or it can be written as "playRole min 2". This is described as "playRole min 2

Design_Role” in terms of the qualified minimum cardinality restriction wherein the name of the filler class is explicitly written (i.e. design role).

Maximum cardinality restriction—describes an anonymous class of things in terms of the maximum number of relationships that an individual of the anonymous class must participate in, along a specific property. It is denoted by “≤ ” in the Description Logic (DL) Syntax. The maximum cardinality restriction describes a class of things in the formal DL Syntax as “≤ playRole 2”, which can also be written as “playRole max 2”. This is described as “playRole max 2 Design_Role” in terms of the qualified maximum cardinality restriction.

Exact cardinality restriction—describes an anonymous class of things in terms of the exact number of relationships that an individual of the anonymous class must participate in, along a specific property. It is denoted by “≤ ” in the Description Logic (DL) Syntax. The exact cardinality restriction describes a class of things in the formal DL Syntax as “= playRole 2”, which can also be written as “playRole equal 2”. Also, it is described as “playRole equal 2 Design_Role” in terms of the qualified exact cardinality restriction.

E.1.7.4.3 hasValue Restriction

The minimum cardinality restriction describes an anonymous class of things in which an individual from anonymous class is related to a specific individual along a specified property. It is denoted by “϶” in the Description Logic (DL) Syntax. The “hasValue Restriction” describes a class of things in the formal DL Syntax as “play ϶ Design_Engineer_Highway”. An example of the “hasValueRestriction” is represented in Figure E-15.

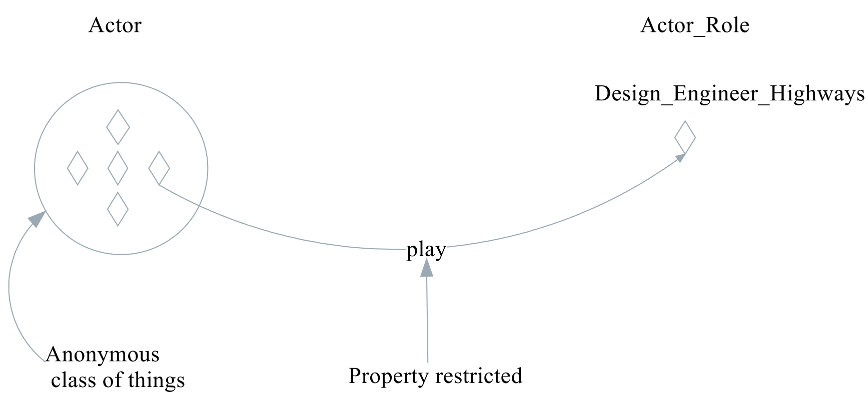

Figure E-15 hasValue restriction

It describes that an anonymous class of things is the one in which an individual of this class is related to a specific individual, the design engineer highways, along a specified property “play”. Although, the “hasValue Restriction” and existential restriction are semantically equivalent, but still there is a slight difference between the two. In the existential restriction, the individual that is a member of an anonymous class of thing is related along a given property “play” to “any” individual that is a member of a specified class, wherein the “hasValue Restriction” the individual from the anonymous class of thing is related to a specific individual along the property “play”.

E.1.8 Step 8—Code Ontology

The detailed taxonomies created in the unified modeling language (UML) for both the core and support concepts were formally coded using the ontology web language (OWL) in the Protégé ontology editor. The OWL was chosen for its' robustness and richness in providing more facilities to express semantics of concepts and represent machine-interpretable content on the web than other languages like XML, RDF and RDF-S. For this purpose, the Protégé 4.0.2, an OWL-based open-source ontology editor (Protégé, 2014) was used to code and represent the transaction domain knowledge. The coding was done in the following three steps.

E.1.8.1 Code Class Hierarchy

The UML based taxonomies of all the core and support concepts were recreated in the Protégé ontology editor using the OWL as a class hierarchy under the classes tab as shown in Figure E-16.

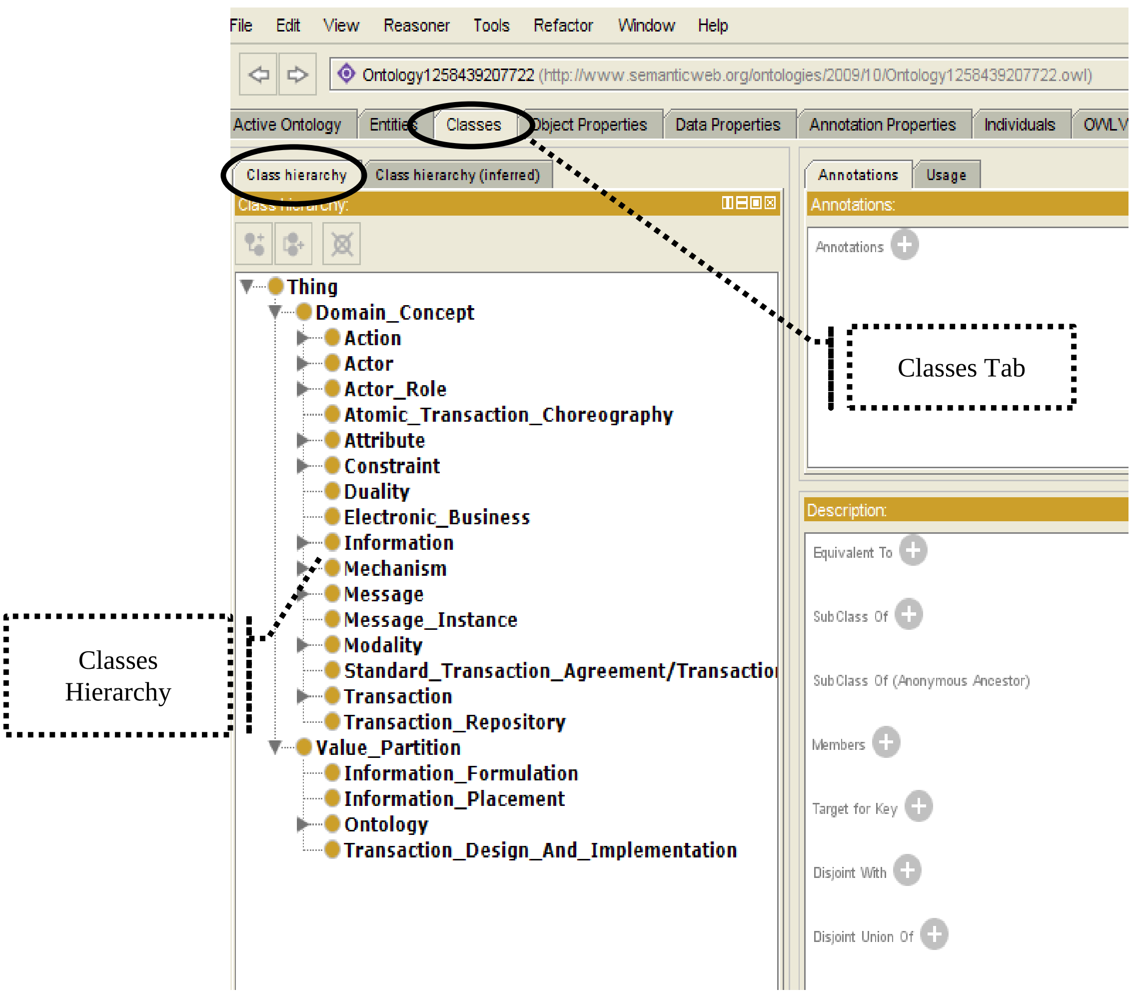

Figure E-16 Class hierarchy representing taxonomies of core and support concept

The class hierarchy shows abstract classes of both the core and support concepts, which were further expanded to develop detailed taxonomies of the core and support concepts. As an example, the detailed taxonomy of the transaction concept is presented in Figure E-17.

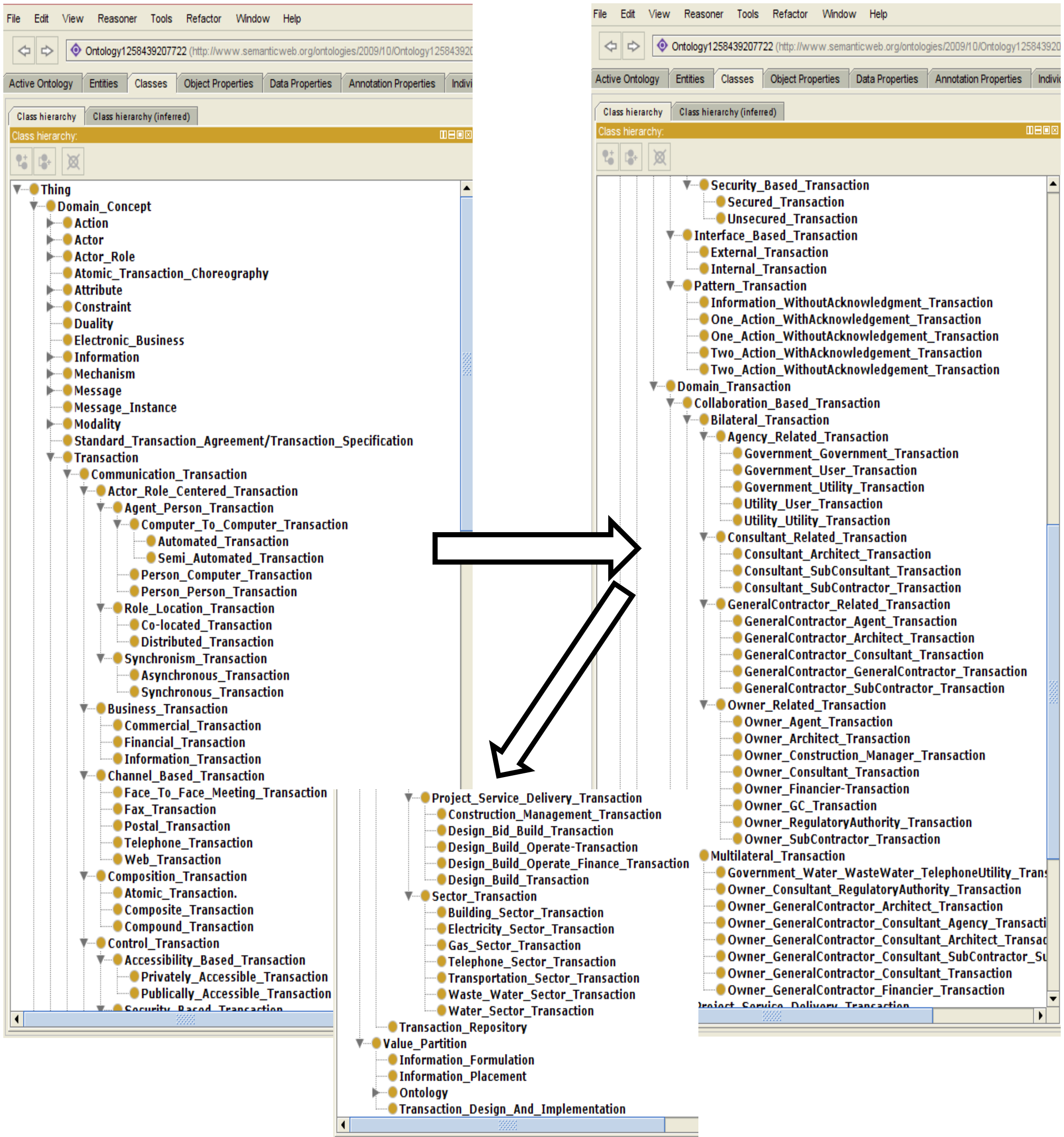

Figure E-17 Transaction taxonomy coded in Protégé ontology editor using ontology web language

E.1.8.2 Code Relationship Hierarchy

The relationship (known as an object property in the Protégé) hierarchy was developed in the Protégé ontology editor under the object properties tab using the OWL as shown in Figure E-18 (a). The directed association relationships shown in the object hierarchy represent the top-level abstract classes, which were expanded to develop sub-classes of each category. As an example, facilitate and formalize directed association relationships were expanded as shown in Figure E-18 (b).

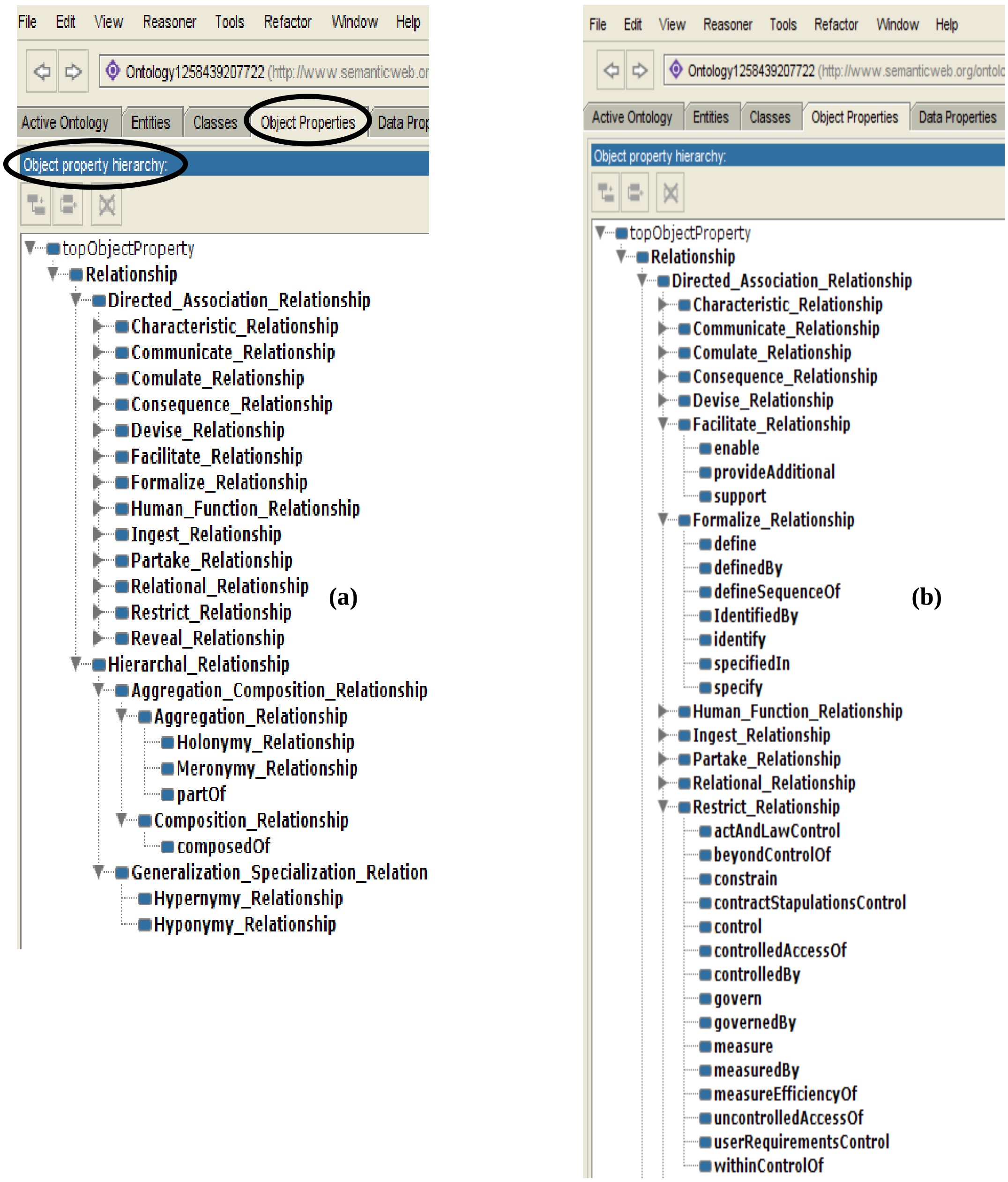

Figure E-18 (a) Abstract object property hierarchy; and (b) Expanded directed associations

E.1.8.3 Code Directed Association and Axioms

The directed associations relationships or properties were used to enrich the knowledge representation through establishing links between concepts and explicitly defining all the three types of axioms: the sub-sumption (is-a), disjointed, and property restriction axioms that have developed in the previous ontology capturing step. As an example, two-action with acknowledgement transaction was explicitly defined in the Protégé ontology editor using the three types of axioms as shown in Figure E-19. Similarly, all the core and support concepts represented in the Trans_Dom_Onto were coded.

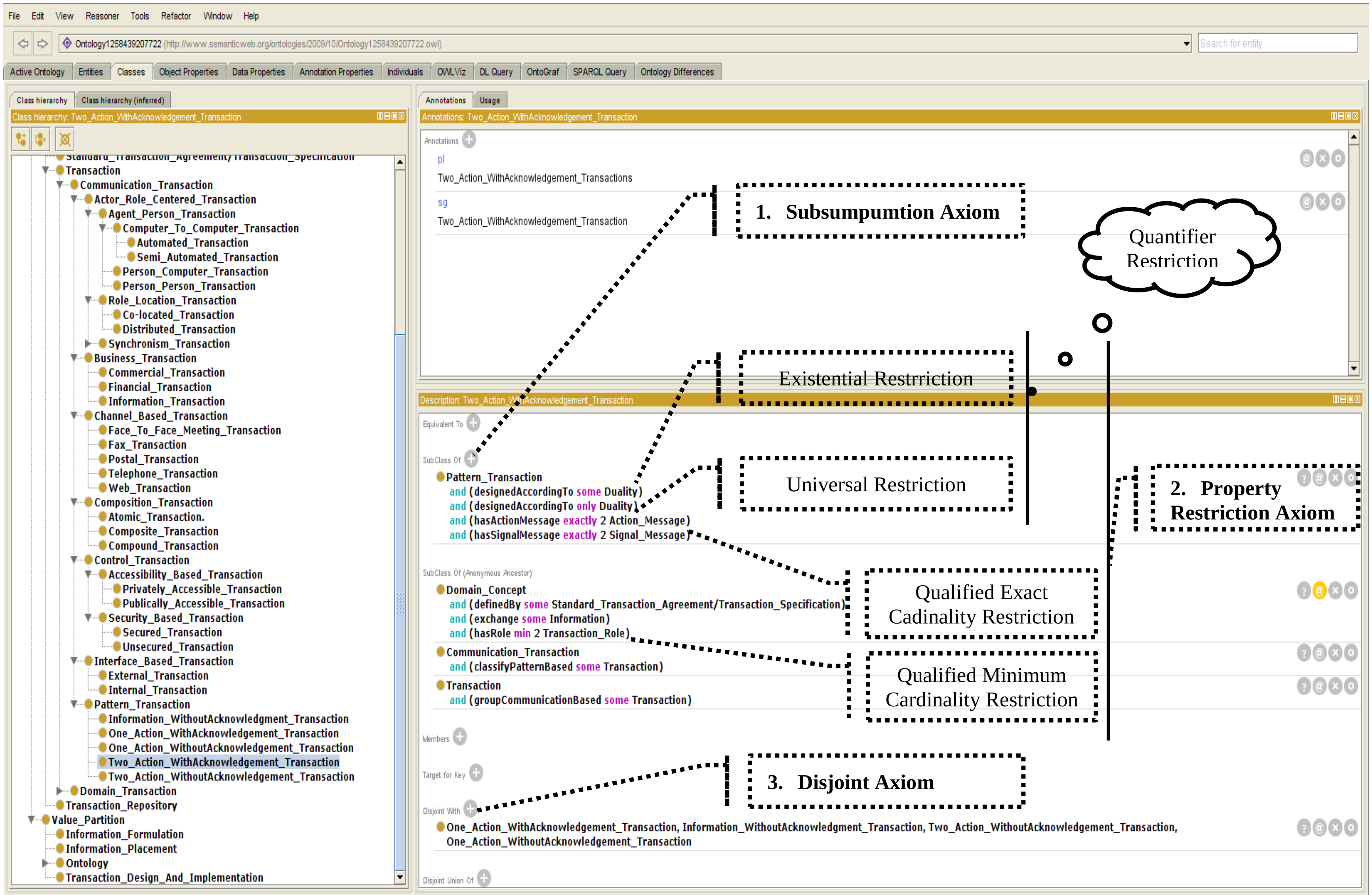

Figure E-19 Axioms coded in Protégé ontology editor to define concepts explicitly

E.1.9 Step 9—Evaluate Ontology

The Trans_Dom_Onto was evaluated using the framework presented in Table E-2. The framework shows the criteria, measures, and tools used to evaluate the Trans_Dom_Onto. The three elements of the ontology evaluation framework are already defined in the Chapter 4.

Table E-2 Ontology evaluation framework

Ontology Evaluation Framework				
Criteria	Measure	Ontology Evaluation Tools		
		Verification		Validation
		Automated Reasoner	Competency Questions	Expert Review
Consistency-Inconsistency error	i. Cirulatory errors	√		
	ii. Partition errors	√		
	iii. Semantic inconsistency errors		√	
Conciseness-Redundency error	i. Grammatical redundency errors	√		
Completeness-Incompleteness error	i. Incomplete concept classification		√	√
Correctness-Class definition error	i. Identity-identify real world class definition		√	√
Clarity-Communication error	i. Class description communication error			√

The Trans_Dom_Onto was verified using Protégé automated description logic reasoners and competency questions, whereas validated through expert review as part of the ontology evaluation. The results of the ontology verification and validation are as follows.

E.1.9.1 Protégé Automated Reasoners Based Verification of the Transaction Domain Ontology

The built-in automated description logic Reasoners in the Protege 4.0.2; such as FaCT++, Pallet and RacerPro 2, were used to check the consistency (circulatory errors and partition errors) and conciseness (grammatical redundancy errors) of the knowledge represented in the Trans_Dom_Onto. The class hierarchy with white background along with different types of reasoners available in the Protégé ontology editor are shown in Figure E-20 (a). The reasoning analysis results are shown in Figure E-20 (b and c), which reflects the term 'Nothing' under the inferred class hierarchy (an automatically generated class hierarchy with pale yellow background). The term "Nothing" describes a super class of things having subclasses of concepts with any one of the errors mentioned above. After running the reasoners, a set of inconsistent classes in red text was found under the super class "Nothing" in the inferred class hierarchy as shown in Figure E-20 (b). Upon checking the erroneous classes, a disjoint or partition error was found, which was fixed accordingly. The automated reasoners were run again to check that the problem is fixed and it was found that the super class "Nothing" was automated deleted or removed from the inferred class hierarchy as shown in Figure E-20 (c), which means that the Trans_Dom_Onto is now consistent and concise.

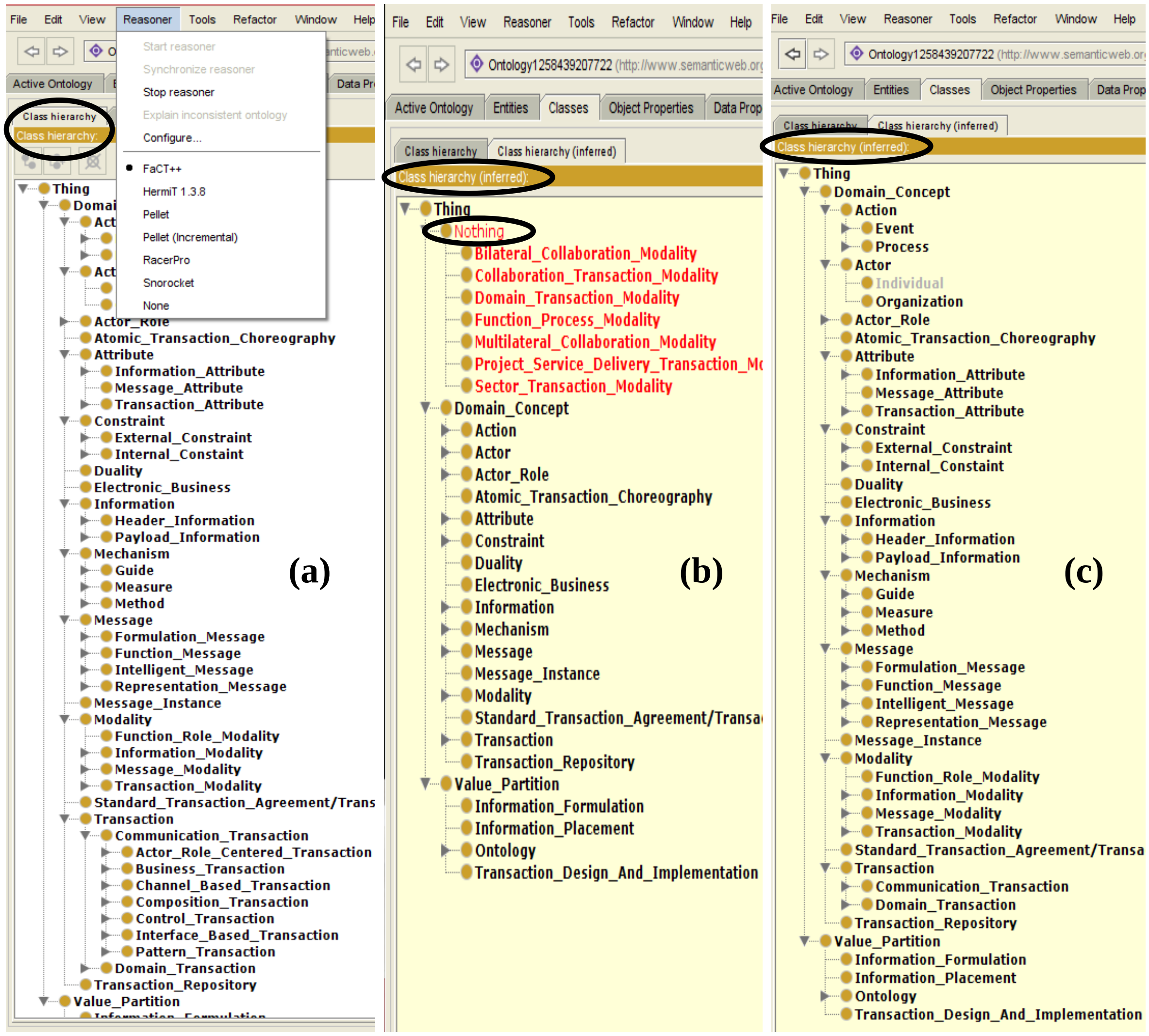

Figure E-20 Reasoners based verification of the transaction domain ontology; (a) Class hierarchy with Protégé automated reasoners; (b) Inconsistent inferred class hierarchy; and (c) Consistent inferred class hierarchy

E.1.9.2 Competency Questions Based Verification of the Transaction Domain Ontology

In the competency questions (CQs) based verification, each CQ was manually checked to assess consistency, completeness, and correctness of the knowledge represented in the Trans_Dom_Onto. The detailed analysis is presented in the multi-sheet Table E-3 wherein the CQs are grouped according to the requirements of the Trans_Dom_Onto. The set of the CQs listed for each requirement is measured for semantic inconsistency errors, incomplete concept classification, and identity errors at three compliance levels: full-compliance, partial-compliance, and non-compliance. A compliance level was checked for each measure against each CQs, which was summed-up and a percentage was calculated. All the measures are explicitly defined under evaluation section of the Chapter 4. The results of the verification analysis are presented on the last sheet of Table E-3, which show a satisfactory compliance with the CQs

Table E-3 Competency questions based verification of the transaction domain ontology—(multi-sheet table)

Competency Question based Verification - Ontology Evaluation											
S. #	**Requirements**	**Competency Questions (CQs)**	**Measures**								
			Semantic Inconsistency Errors			Incomplete Concept Classification			Identity Errors		
			Compliance with Measures								
			F	P	N	F	P	N	F	P	N
"F" stands for Full Compliance; "P" stands Partial Compliance; and "N" stands for Non Compliance											
1	The ontology should capture the transaction concept and it's extensions.	**Competency Questions relating Transaction**									
		Competency Questions relating Transaction Communication Modality									
		i. Are transactions designed based on different design patterns?	√			√			√		
		ii. Are transactions defined based on the exchange of the physical, financial, and information resources?	√			√			√		
		iii. Is a transaction defined based on whether it is external or internal to the organization?	√			√			√		
		iv. Is a transaction formalized based on the location of transaction roles?	√			√			√		
		v. Are transactions defined based on the flow of information between persons and computer agents?	√			√				√	
		vi. Are transactions designed based on the response timings?	√			√			√		
		vii. Are transactions defined based on the means of transmission?	√			√			√		
		viii. Are transactions defined based on the means of transmission?	√			√			√		
		ix. Does transaction design incorporate transaction security?	√			√			√		
		Competency Questions relating Domain Transaction Modality									
		i. Are transactions designed and grouped according to bi-lateral and multi-lateral collaboration?	√			√			√		
		ii. Are transactions defined based on the sector or application area?	√			√			√		
		iii. Does transaction design incorporate different modes of the project delivery as one of the governing factors for the design of transactions?	√			√			√		
		iv. Does the Trans_Dom_Onto reflect the support processes defined in the IC-Pro-Onto?	√				√			√	

Competency Question based Verification - Ontology Evaluation

S. #	Requirements	Competency Questions (CQs)	Measures								
			Semantic Inconsistency Errors			Incomplete Concept Classification			Identity Errors		
			Compliance with Measures								
			F	P	N	F	P	N	F	P	N
"F" stands for Full Compliance; "P" stands Partial Compliance; and "N" stands for Non Compliance											
2	The ontology should reflect the concept of message / message template and it's extensions.	**Competency Questions relating Message**									
		i. Are messages classified based on whether they are formulated as verbal or written messages?	√				√		√		
		ii. Does a message design incorporate the way information is to be represented in a message?	√			√			√		
		iii. Are messages defined based on the function they perform in an information exchange scenario?	√			√			√		
		iv. Does a message design incorporate the level to which the information represented in the message is computer interpretable?	√			√			√		
3	The ontology should represent the concept of actor and actor role and it's extensions.	**Competency Questions relating Actor - Actor Role**									
		i. Is transaction role (sender/receiver role) represented in the actor taxonomy?	√			√			√		
		ii. Are the actor roles classified based on various core functions in the domain of infrastructure management?	√				√			√	
		iii. Is a transaction role related to a message?	√			√				√	
		iv. Is an actor related to a message instance?	√			√					√

Competency Question based Verification - Ontology Evaluation

S. #	Requirements	Competency Questions (CQs)	Measures: Semantic Inconsistency Errors			Measures: Incomplete Concept Classification			Measures: Identity Errors		
			Compliance with Measures								
			F	P	N	F	P	N	F	P	N
"F" stands for Full Compliance; "P" stands Partial Compliance; and "N" stands for Non Compliance											
4	The ontology should reflect the information concept and it's extensions	**Competency Questions relating Information**									
		i. Does the ontology represent the header and payload information that is exchanged in a transaction?	√				√		√		
		ii. Does a message represent information?	√			√				√	
		iii. Is a message composed of header and payload information ?	√			√			√		
		Competency Questions relating Payload Information									
		i. Does the payload information modality classify payload information based on the placement of the information in the message?	√				√		√		
		ii. Does the payload information modality classify payload information based on the way information is formulated in a message?	√			√				√	
		iii. Does the payload information modality classify payload information based on the mode through which information is transmitted between the collaboration partners?	√				√		√		
		Competency Questions relating Header Information Context									
		i. Does the ontology represent the preamble, delivery, and service header information?	√			√			√		
		ii. Does the delivery header information classify header information based actor, actor role, temporal, and security information?	√			√			√		
		iii. Does the services header information classify header information based on message and transaction general information?	√			√			√		

Competency Question based Verification - Ontology Evaluation														
S. #	**Requirements**	**Competency Questions (CQs)**	**Measures**								
			Semantic Inconsistency Errors			Incomplete Concept Classification			Identity Errors		
			Compliance with Measures								
			F	P	N	F	P	N	F	P	N
"F" stands for Full Compliance; "P" stands Partial Compliance; and "N" stands for Non Compliance											
5	The ontology needs to reflect attributes and modalities of various concepts.	**Competency Questions relating Attribute and Modality**									
		Competency Questions relating Transaction Attribute									
		i. Does the ontology represent transaction function as a characteristic of a transaction?	√			√				√	
		ii. Does the ontology represent transaction dependency as a property of transaction?	√			√			√		
		iii. Does the knowledge representation incorporate logical dependency as one of the attributes of a transaction?	√			√			√		
		iv. Does the geographic dependency characterize a transaction?	√			√			√		
		v. Does the ontology represent cyber dependency of a transaction as one of the primary ingredients for transaction design, implementation, and management?	√			√			√		
		vi. Does the ontology represent control attribute as one of the characteristics of a transaction?	√			√			√		
		vii. Does the ontology reflect variable and fixed costs of a transaction?	√			√			√		
		viii. Does the knowledge representation incorporate administrative and transmission costs of a transaction?	√			√			√		
		ix. Does the knowledge incorporate transaction efficiency as one of the performance characteristics of a transaction?	√				√			√	
		Competency Questions relating Information Attribute									
		i. Does the ontology incorporate attributes of the header information represented in the message templates?	√			√			√		
		ii. Does the ontology represent attributes of the pyload information reflected in the message templates?	√				√		√		

Competency Question based Verification - Ontology Evaluation											
S. #	**Requirements**	**Competency Questions (CQs)**	**Measures**								
			Semantic Inconsistency Errors			Incomplete Concept Classification			Identity Errors		
			Compliance with Measures								
			F	P	N	F	P	N	F	P	N
"F" stands for Full Compliance; "P" stands Partial Compliance; and "N" stands for Non Compliance											
6	The ontology needs to represent mechanism and it's extensions.	**Competency Questions relating Mechanisms**									
		Competency Questions relating Mechanisms - Guides									
		i. Does the mechanism taxonomy incorporate guides required to design, implement, and manage transactions?	√			√			√		
		ii. Does the mechanism taxonomy represent different strategies that affects the design and implementation of transactions?	√			√				√	
		iii. Does the mechanism taxonomy reflect best practices required for the design and implementation of electronic transaction?	√				√		√		
		Competency Questions relating Mechanisms - Methods (Transaction Channel and Transaction Archival)									
		i. Does the mechanism taxonomy incorporate oral and written means of communication?	√			√			√		
		ii. Does the mechanism taxonomy represent electronic and non-electronic communication channels?	√			√			√		
		iii. Does the mechanism taxonomy represent transaction archival steps?	√			√			√		
		Competency Questions relating Mechanisms - Measures									
		i. Does the knowledge representation reflect objective and subjective metrics for the measurement of transaction efficiency?	√				√		√		

Competency Question based Verification - Ontology Evaluation											
S. #	**Requirements**	**Competency Questions (CQs)**	**Measures**								
			Semantic Inconsistency Errors			Incomplete Concept Classification			Identity Errors		
			Compliance with Measures								
			F	P	N	F	P	N	F	P	N
"F" stands for Full Compliance; "P" stands Partial Compliance; and "N" stands for Non Compliance											
7	The ontology needs to model transaction constraints.	**Competency Questions relating Transaction Constraints**									
		i. Does the constraint taxonomy represent internal and external constraints hampering the design and implementation of transactions?	√				√			√	

Competency Question based Verification - Ontology Evaluation											
S. #	**Requirements**	**Competency Questions (CQs)**	**Measures**								
			Semantic Inconsistency Errors			Incomplete Concept Classification			Identity Errors		
			Compliance with Measures								
			F	P	N	F	P	N	F	P	N
"F" stands for Full Compliance; "P" stands Partial Compliance; and "N" stands for Non Compliance											
8	The ontology needs to capture the notion of generalization – specialization and composition aggregation in terms of classification and decomposition of concepts.	**Competency Questions relating Relationships**									
		i. Does the transaction domain knowledge represents hierarchal (is-a) and association relationships?	√			√			√		
		ii. Does the relationship taxonomy incorporate aggregation-composition relationships?	√			√			√		
		Score of each measure for full, partial, and non compliance	51			40	11		40	10	1
		Total score of each measure (sum of full, partial, and non compliance	51			51			51		
		Percentage score of each measure	100			79	21		79	19	2

E.1.9.3 Expert Review Based Validation of the Transaction Domain Ontology

The Trans_Dom_Onto was validated through domain experts as part of the ontology evaluation. The ontology validation was conducted using a survey based approach where individuals from the industry were identified, selected, and interviewed. The interviewees or respondents were given a structured questionnaire developed to reflect questions related to clarity, completeness, and correctness of the knowledge representation. The questionnaire reflects the research background information, goals and objectives, the role of the respondents, information confidentiality, and risks and its remedial measures. The questionnaire also discusses the characteristics of an interviewee, the interview process and its duration. The questionnaire is a comprehensive document capturing almost all information that the experts require during the interview and the Univeristy of British Columbia needs to fulfill. The Trans_Dom_Onto validation questionnaire is attached at Appendix G. The respondent’s profile, their familiarity with the domain, and the Trans_Dom_Onto validation results are as follows.

E.1.9.3.1 Respondent Profile and Familiarity with the Domain of Interest

Three respondents were identified, selected, and interviewed based on the criteria given in the questionnaire. Their general profile information; like the name, designation, organization name, telephone number, and E-mail address is kept confidential whereas their technical profile information is presented in presented in Table E-4.

Table E-4 Respondent profile information

S. No.	Information relating Respondent Profile			
A.	**Respondent General Profile**	**Respondent A**	**Respondent B**	**Respondent C**
1	Respondent Name	Kept Confidential	Kept Confidential	Kept Confidential
2	Respondent Position/Designation/Title			
3	Respondent Organization Name			
4	Respondent Tel No.			
5	Respondent E-mail Address			
B.	**Respondent Technical Profile**			
6	Years of Experience	18	17	15+
7	Field/Sector of Experience	Municipal and Transportation	Municipal and Civil Engineering	Construction and Project Management

E.1.9.3.2 Respondent’s Familiarity with the Domain of Interest

The respondents' familiarity with different infrastructure sectors, data/information modeling, and communication formalization is presented in Table E-5.

Familiarity with infrastructure sectors—a per the average score, the respondents were extremely familiar (05) with the transportation sector, whereas moderately familiar (4 and above) with other three infrastructure sectors. The respondents' extreme familiarity with the transportation sector was due to their relevant educational background and past experience in the same area. The data represent that the selected respondents were a good fit to evaluate the Trans_Dom_Onto in the domain of infrastructure management.

Table E-5 Respondents familiarity with different infrastructure sectors

Respondents' Familiarity with Infrastructure Sectors, Information Modelling, and Communication Formalization					
Familiarity Questions	**Respondents**			**Average Score**	**Legends**
	A	**B**	**C**		
	Agreement Rating				
Familiarity with Infrastructure Sectors					
Transportation	5	5	5	**5.00**	0 Unable to Rate
Water	5	4	4	**4.33**	1 Not at all Familiar
Wastewater	5	4	3	**4.00**	2 Slightly Familiar
Solidwaste Management	4	5	3	**4.00**	3 Somewhat Familiar
Familiarity with Data and Information Modelling					4 Moderately Familiar
Information Modelling	4	4	4	**4.00**	5 Extremely Familiar
Familiarity with Communciation Formalization					
Communciation/Data Exchange Formalization	5	4	3	**4.00**	

Familiarity with data or information modeling—the respondents were moderately familiar with data or information modeling as per the average score (4) shown in Table E-5. This shows that the respondents were actively involved in the data or information modeling at the municipal level.

Familiarity with data exchange or communication formalization—the respondents were moderately familiar with the communication formalization as per the average score (4) represented in Table E-5. The data shows that the respondents were actively involved in formalizing work processes and communications at the municipal level; however, they were doing it on an ad hoc basis.

E.1.9.3.3 Clarity of the Knowledge Represented in the Transaction Domain Ontology

The clarity means how understandable a knowledge representation is. The respondents were asked to rate each concept for clarity on a likert scale of 1 (strongly disagree) to 5 (strongly agree). The response of the three respondents is recorded as shown in Table E-6. For each concept, the average of the three responses is calculated, which ranges from 4 (agree) to 5 (strongly agree). The result shows a universal agreement of the respondents on the clarity of the knowledge represented in the Trans_Dom_Onto. The respondent's scores are higher for some concepts that are either very common (e.g. E-mail) or mostly related to the domain of infrastructure management (e.g. Owner_Architect_Transaction).

The data was further analyzed for statistical significance to prove that there is no significant difference; (i) between the response of each respondent, and (ii) between the responses for each concept. The data recorded was analyzed using analysis of variance (ANOVA) two-factor without replication. This approach was selected as the recorded data included two independent variables: respondents (in columns) and concepts (in rows).

Table E-6 Clarity of the knowledge represented in the transaction domain ontology

Knowledge Representation (Ontology) Clarity					
Concepts	**Respondents**			**Average Score**	**Legends**
	A	**B**	**C**		
	Agreement Rating				
Transaction					
Publically_Accessible_Transaction	4	4	5	**4.33**	0 Unable to Rate
One_Action_WithAcknowledgement_ Transaction	4	4	4	**4.00**	
Owner_Architect_Transaction	5	5	5	**5.00**	1 Strongly Disagree
Transportation_Sector_Transaction	5	5	4	**4.67**	
Actor Role					2 Disagree
Consultant_Role	5	5	5	**5.00**	
Receiver_Role	5	4	4	**4.33**	3 Neither Agree nor Disagree
Information					
Message_Body_Information	4	5	4	**4.33**	
Transaction_General_Information	5	5	5	**5.00**	4 Agree
Message					
Acknowledgement_ Message	5	5	5	**5.00**	5 Stronlgy Agree
Soft_Message	5	4	3	**4.00**	
Channel					
E-mail_Channel	5	5	5	**5.00**	
Attribute					
Transaction_Duration_Attribute	5	5	2	**4.00**	

The null hypothesis states that there is no significant difference between the respondent' responses and that there is a universal agreement among the respondents on the clarity of the knowledge represented in the Trans_Dom_Ono. The result of the statistical analysis is shown in Table E-7. The analysis was conducted at a confidence level of 95% using an alpha (α) factor of 0.05. The rows and columns in Table E-7 represent the concepts and respondents respectively.

Table E-7 ANOVA two-factor without replication test for knowledge representation clarity

	Anova: Two-Factor Without Replication					
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Rows	6.22222222	11	0.56565657	1.39130435	0.24473949	2.25851836
Columns	1.72222222	2	0.86111111	2.11801242	0.14413555	3.44335678
Error	8.94444444	22	0.40656566			
Total	16.8888889	35				

The statistical results show that the value of "F" is less than "F_{crit}" (2.11<3.44) with p-value 0.144 greater than the alpha factor 0.050, indicating that there is no significant difference and the null hypothesis (no statistical difference between the respondents' responses) is to be accepted, which means all the respondents have a universal agreement on the clarity of the knowledge represented in the Trans_Dom_Onto.

E.1.9.3.4 Completeness of the Knowledge Represented in the Transaction Domain Ontology

The completeness of the knowledge representation was assessed in terms of the incompleteness. The respondents were presented with the set of key concepts that are required for the design, implementation, and management of transactions in the domain of infrastructure management. The respondents were asked to rate the given key concepts on a scale of 1 (strongly disagree) to 5 (strongly agree) and identify other key concepts that are important for the design, implementation, and management of transaction. The assessment in terms of the agreement is presented in Table E-8. The average score for different key concepts ranges from 4.33 to 5, which means that the respondents have a universal agreement on the completeness of the core knowledge represented in the Trans_Dom_Onto.

Table E-8 Completeness of the knowledge represented in the transaction domain ontology

Knowledge Representation (Ontology) Completeness					
	Respondents			**Total Score**	**Legends**
	A	**B**	**C**		
Key Concepts	**Agreement Rating**				
Transaction	5	5	5	**5.00**	0 Unable to Rate
Actor	5	4	5	**4.67**	1 Strongly Disagree
Actor Role	5	5	4	**4.67**	2 Disagree
Information	4	5	4	**4.33**	3 Neither Agree nor Disagree
Message	5	5	5	**5.00**	4. Agree
Channel	5	5	5	**5.00**	5 Stronlgy Agree

The respondents also identified a set of other concepts (e.g. action, general user role, sub-consultant role) that they thought were important for the design and implementation of transactions in the domain of infrastructure management. Those concepts were already represented in the ontology. The data collected was also statistically analyzed and results are shown in Table E-9.

Table E-9 ANOVA two-factor without replication test for knowledge representation completeness

Anova: Two-Factor Without Replication						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Rows	1.11111111	5	0.22222222	1.17647059	0.38518911	3.32583453
Columns	0.11111111	2	0.05555556	0.29411765	0.75141884	4.10282102
Error	1.88888889	10	0.18888889			
Total	3.11111111	17				

The result show that the value of "F" is less than "F_{crit}" (0.29<4.10) with p-value 0.75 greater than the alpha factor 0.050, indicating that there is no significant difference and the null hypothesis (no statistical difference between the respondents' responses) is to be accepted, which means all the respondents have a universal agreement on the completeness of the knowledge represented in the Trans_Dom_Onto.

E.1.9.3.5 Correctness of the Knowledge Represented in the Transaction Domain Ontology

The knowledge represented in the Trans_Dom_Onto was assessed for correctness, which means that the ontology correctly describe class definitions from a real world perspective. A set of concepts from the Trans_Dom_Onto was presented to the respondents for assessment and they were requested to rate each concept on a scale of 1 (strongly disagree) to 5 (strongly agree). The assessment result is presented in Table E-10.

Table E-10 Correctness of the knowledge represented in the transaction domain ontology

Knowledge Representation (Ontology) Correctness					
	Respondents			**Average Score**	**Legends**
	A	**B**	**C**		
Concepts	**Agreement Rating**				
Transaction					0 Unable to Rate
Automated Transaction	5	5	5	**5.00**	
Web_Transaction	4	4	4	**4.00**	
Owner_GC_Consultant_ Transaction	5	5	4	**4.67**	1 Strongly Disagree
Water_Sector_Transaction	5	5	4	**4.67**	
Actor Role					
Local_Government_Role	5	5	5	**5.00**	2 Disagree
Sender_Role	4	5	4	**4.33**	
Information					
Design_Report_Information	5	5	5	**5.00**	3 Neither Agree nor
Temporal_Information	4	5	4	**4.33**	Disagree
Message					
Receipt_Acknowledgement_Message	5	4	5	**4.67**	
Fully_Structured_Message	4	4	5	**4.33**	4 Agree
Channel					
Server_Based_Channel	5	5	4	**4.67**	
Attribute					5 Strongly Agree
Transmission_Cost_ Attribute	5	5	4	**4.67**	
Constraint					
Transaction_Design_ Requirement_Constraint	4	4	4	**4.00**	
Relationship					
exchangedIn	4	5	4	**4.33**	

The average score calculated for each concept ranges from 4 (agree) to 5 (strongly agree) indicating that there is a universal agreement of the respondents on the correctness of the knowledge represented in the Tran_Dom_Onto. The assessment results were further tested for statistical significance using the ANOVA two-factor without replication techniques. The result of the statistical analysis is shown in Table E-11.

Table E-11 ANOVA two-factor without replication test for knowledge representation correctness

Anova: Two-Factor Without Replication						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Rows	4.4047619	13	0.33882784	1.72897196	0.11380627	2.11916569
Columns	0.9047619	2	0.45238095	2.30841121	0.11944611	3.36901636
Error	5.0952381	26	0.1959707			
Total	10.4047619	41				

The results show that the value of "F" is less "F_{crit}" (2.30<3.36) and the P-value is greater than the alpha factor (0.05), indicating that there is no statistical significance between the responses of the three respondents for the given set of concepts, and the null hypothesis is to be accepted, which means there is universal agreement of the respondents on the correctness of the transaction domain knowledge represented in the Trans_Dom_Onto.

E.1.9.3.6 Overall Assessment of the Knowledge Represented in the Transaction Domain Ontology

Finally, the respondents were asked to provide an overall assessment of the knowledge represented in the Trans_Dom_Onto as part of the ontology validation. The result of the overall assessment is presented in Table E-12, indicating that the respondents are universally agreed on the clarity, completeness, and correctness of the content represented in the ontology. During validation, the respondents raised several important points that were answered on the spot.

Table E-12 Transaction domain ontology overall assessment

Knowledge Representation (Ontology) Validation, Overall Assessment					
	Respondents			Average Score	Legends
	A	B	C		
Overall Assessment	Agreement Rating				
Does the ontology provide a clear, correct, and complete representation of the transaction knowledge in the area of infrastructure management?	5	5	4	**4.67**	0 Unable to Rate 1 Strongly Disagree 2 Disagree 3 Neither Agree nor Disagree 4 Agree 5 Strongly Agree

E.1.10 Step 10—Document Ontology

In this step, the knowledge represented in the Trans_Dom_Onto was documented for future use through developing application level ontologies and software applications.

Appendix F Tangible Capital Asset Ontology Evaluation

F.1 Evaluation of Tangible Capital Asset Ontology

This appendix captures the results of the TCA_Onto evaluation in terms of verification and validation. Three tools were used to evaluate the ontology: automated protégé reasoners, competency questions, and expert review. The TCA_Onto verification was done using the automated protégé reasoners and competency questions, whereas validation was completed using expert review.

F.1.1 Protégé Automated Reasoner-based Verification of the Tangible Capital Asset Ontology

The results of the Protégé automated reasoner based verification of the TCA_Onto is presented Figure F-1. The automated Protégé reasoners (Protégé, 2014) are applications built-in to Protégé that can automatically check the consistency and conciseness of the knowledge representation. Three reasoners—FaCT++, Pallet, and RacerPro 2—were used to verify the class hierarchy represented in the TCA_Onto as shown in Figure F-1 (a). The automated reasoners were run to check for inconsistencies in the TCA_Onto. After running the reasoners, an inferred hierarchy was generated that was an automatically generated class hierarchy of the TCAs. The inferred hierarchy shows a super class, “Nothing” that represents all inconsistent classes in red text. In the verification of the TCA_Onto, a set of the inconsistent TCAs classes was found under the super class “Nothing” in the inferred hierarchy as shown in Figure F-1 (b). The TCA class hierarchy was checked for errors and all inconsistent classes were fixed. The class hierarchy is said to be free of errors if the super class “Nothing” disappears from the inferred class hierarchy as shown in Figure F-1 (c). This indicates that the TCA_Onto is consistent and concise.

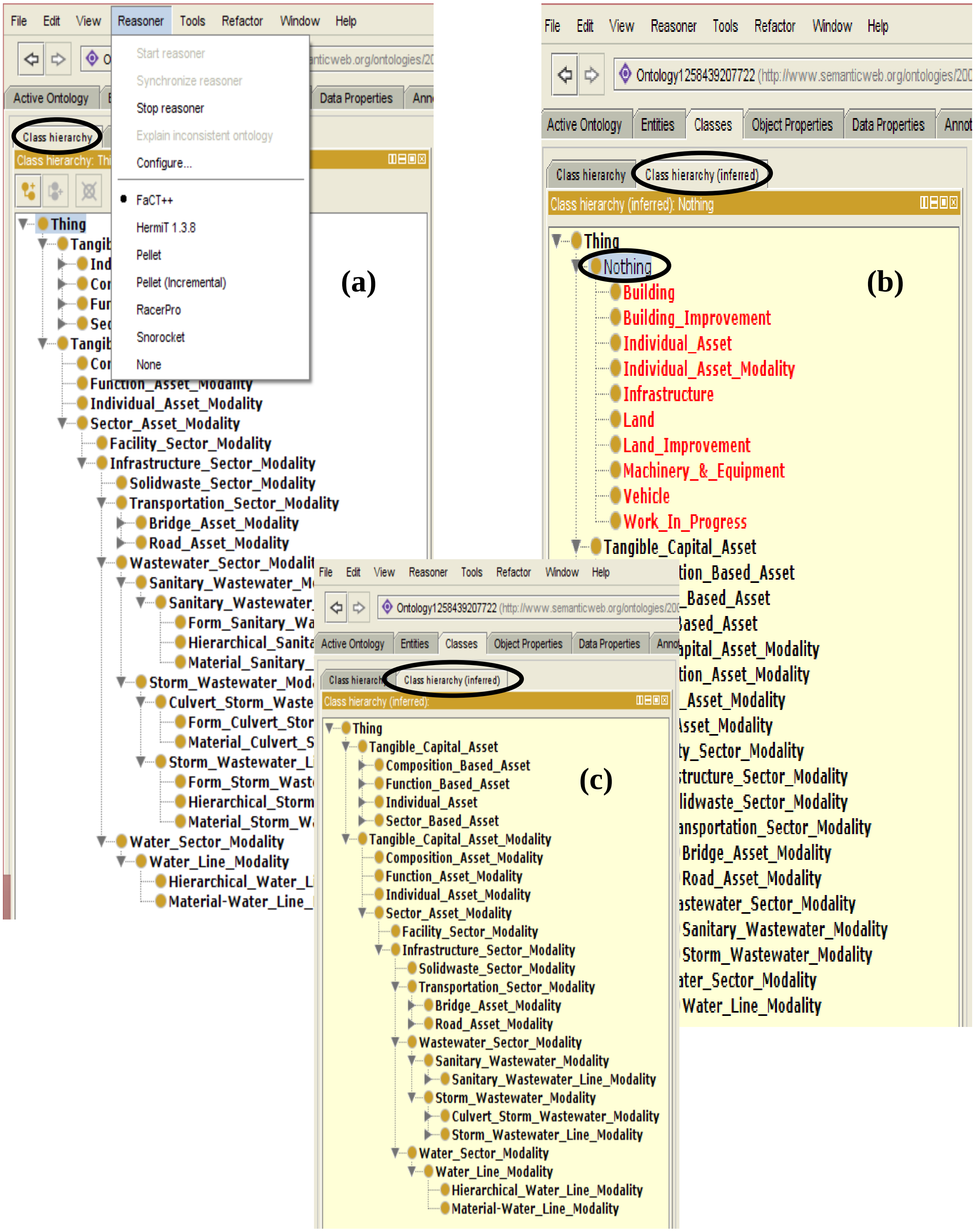

Figure F-1 Reasoners based verification of tangible capital asset ontology; (a) Class hierarchy with Protégé automated reasoners; (b) Inconsistent inferred class hierarchy; and (c) Consistent inferred class hierarchy

F.1.2 Competency Question-based Verification of the Tangible Capital Asset Ontology

The results of the CQ based verification of the knowledge represented in the TCA_Onto are presented in Table F-1.

Table F-1 Competency questions based verification of the tangible capital asset ontology

Competency Question based Verification - Ontology Evaluation										
S. #	**Requirements based Competency Questions (CQs)**	**Measures**								
		Semantic Inconsistency Errors			Incomplete Concept Classification			Identity		
		Compliance with Measures								
		F	P	N	F	P	N	F	P	N
"F" stands for Full Compliance; "P" stands Partial Compliance; and "N" stands for None Compliance										
1	**Requirement # 1** The TCA_Onto should capture tangible capital asset with specific focus on transportation, water, wastewater, and solid waste management.									
	i. Does the ontology represent assets related to the transportation system?	1			1			1		
	ii. Does the ontology define different types of bridges?	1			1			1		
	iii. Does the ontology specify water system assets?	1			1			1		
	iv. Are wastewater system assets identified and defined in the ontology?	1			1			1		
	v. Does the ontology reflect tangible capital assets related to solid waste management?	1				1			1	
	vi. Does the ontology capture different types of facility asset?	1				1			1	
2	**Requirement # 2** The TCA_Onto should represent the notion of hierarchical classification of concepts.									
	i. Does the ontology represent tangible capital asset knowledge according to the notion of generalization-specialization of concepts?	1			1			1		
3	**Requirement # 3** The TCA_Onto should represent the notion of composition-aggregation of concepts.									
	i. Is the tangible capital asset knowledge organized according to the notion of composition-aggregation of concepts?	1			1			1		
4	**Requirement # 4** The TCA_Onto should reflect various modalities and attributes of concepts.									
	i. Does the ontology capture attributes of the tangible capital asset?	1			1			1		
5	**Requirement # 5** The TCA_Onto should represent relationships among concepts.									
	i. Does the ontology incorporate a variety of relationships between concepts?	1			1			1		
	Score of each measure for full, partial, and non compliance	10			8	2		8	2	
	Total score of each measure (sum of full, partial, and non compliance	10			10			10		
	Percentage score of earch measure	100			80	20		80	20	

F.1.3 Expert Review based Validation of the Tangible Capital Asset Ontology

The TCA_Onto validation was conducted using expert review approach. An interview was scheduled with a set of respondents identified in the domain of infrastructure management to evaluate the TCA_Onto. A structured questionnaire was developed that was presented to the respondents. The respondents were supposed to answer all the questions reflected in the questionnaire.

The questionnaire was composed of six sections. The respondents' profile and familiarity with the domain of infrastructure management was presented in the first and second section respectively. The questions related to clarity, completeness, and correctness of the knowledge represented in the TCA_Onto were presented in the third, fourth, and fifth sections respectively. Finally, a question related to the overall assessment of the TCA_Onto was presented in the sixth section. Also, the questionnaire incorporated the research background, purpose and objective of the research, roles of the respondents, data confidentiality, and glossary of items. The questionnaire is attached at Appendix H

F.1.3.1 Respondents Profile Information

The respondents (A, B, and C) technical profile information is presented in Table F-2. The rich and related experience of the respondents in the area of infrastructure management made them suitable candidates to evaluate the TCA_Onto.

Table F-2 Respondents' profile information

S. No.	**Information relating Respondent Profile**			
A.	**Respondent General Profile**	**Respondent A**	**Respondent B**	**Respondent C**
1	Respondent Name	Kept Confidential	Kept Confidential	Kept Confidential
2	Respondent Position/Designation/Title			
3	Respondent Organization Name			
4	Respondent Tel No.			
5	Respondent E-mail Address			
B.	**Respondent Technical Profile**			
6	Years of Experience	18	17	15+
7	Field/Sector of Experience	Municipal and Transportation	Municipal and Civil Engineering	Construction and Project Management

F.1.3.2 Respondents' Familiarity

The respondents' familiarity with a different domain of interests is presented in Table F-3. The familiarity of the respondents was assessed on a rating scale of 1 (not at all familiar) to 5 (extremely familiar). Every respondent recorded his/her familiarity with different domains of interest and an average score was calculated. The average score of the respondents' familiarity with different infrastructure sectors ranged from 4 (moderately familiar) to 5 (extremely familiar) whereas the average score for data modeling and TCA reporting was 4 (moderately familiar). The results indicate that respondents are moderately familiar with different infrastructure sectors, data or information modeling, and Tangible Capital Asset (TCA) Reporting.

Table F-3 Respondents’ familiarity with infrastructure sectors, data modeling, and tangible capital asset reporting

Respondents' Familiarity with Infrastructure Sectors, Information Modelling, and PSAB-3150 Reporting Requirements					
Familiarity Questions	**Respondents**			**Average Score**	**Legends**
	A	**B**	**C**		
	Agreement Rating				
Familiarity with Infrastructure Sectors					
Transportation	5	5	5	**5.00**	0 Unable to Rate
Water	5	4	4	**4.33**	1 Not at all Familiar
Wastewater	5	4	3	**4.00**	2 Slightly Familiar
Solidwaste Management	4	5	3	**4.00**	3 Somewhat Familiar
Familiarity with Data and Information Modelling					4 Moderately Familiar
Information Modelling	4	4	4	**4.00**	5 Extremely Familiar
Familiarity with PSAB-3150 Reporting Requirement					
Tangible Capital Asset Reporting	5	4	3	**4.00**	

F.1.3.3 Clarity of the Knowledge Represented in the Tangible Capital Asset Ontology

The clarity means how understandable the TCA_Onto is. To assess the clarity of the knowledge representation, a set of TCAs was identified in the transportation, water, wastewater, solidwaste management, and facility sector. The respondents (A, B, & C) were asked to furnish your agreement on a scale of 1 (strongly disagree) to 5 (strongly agree). All the respondents rated the TCAs represented in the questionnaire as shown in Table F-4 and an average score was calculated. The average score of all concepts were ranged from 4 (agree) to 5 (strongly agree), which means the respondents were in universal agreement on the clarity of the knowledge represented in the TCA_Onto.

The results presented in Table F-5 were also tested for statistical significance using the analysis of variance (ANOVA) two-factor without replication technique. A confidence level of 95% or alpha factor of 0.05 was selected for the statistical analysis. The null hypothesis states that there is no statistical significance or difference between the responses of the three respondents and that they are in universal agreement. The results of the statistical analysis are presented in Table F-5 wherein the value of “F” is less than “F_{cri}” (1.00<3.19) and the value of “p” is greater than the alpha factor (0.37>0.05), which means that there is no statistical significance between the responses and the null hypothesis is accepted. The statistical results indicate that the respondents are in universal agreement on the clarity of the TCA_Onto.

Table F-4 Clarity of the knowledge represented in the tangible capital asset ontology

Knowledge Representation (Ontology) Clarity					
Concepts (Tangible Capital Asset)	Respondents			Average Score	Legends
	A	B	C		
	Agreement Rating				
Infrastructure Sector Asset					
Transaportation Sector Asset					
Urban_Freeway	5	5	5	**5.00**	0 Unable to Rate
Rural_Freeway	5	5	5	**5.00**	
Urban_Collector_Road	5	5	5	**5.00**	
Rural_Collector_Road	5	5	5	**5.00**	
Urban_Local_Road	5	5	5	**5.00**	1 Strongly Disagree
Rural_Local_Road	5	5	5	**5.00**	
Alley_Pathway	5	4	4	**4.33**	
Twin_Tube_Tunnel	4	4	4	**4.00**	
Retaining_Wall	5	5	5	**5.00**	2 Disagree
Transit_Train	4	4	5	**4.33**	
Traffic_Signal	5	5	4	**4.67**	
Water Sector Asset					
Water_Line	5	5	5	**5.00**	3. Neither Agree
Tank	5	5	5	**5.00**	nor Disagree
Reservoir	5	5	5	**5.00**	
Meter	5	5	5	**5.00**	
Wastewater Sector Asset					
Sanitary_Wastewater_Line	5	5	5	**5.00**	4. Agree
Storm_Wastewater_Line	5	5	5	**5.00**	
Manhole	5	4	5	**4.67**	
Culvert	5	5	5	**5.00**	
Pump	5	5	5	**5.00**	5 Strongly Agree
Solidwaste Management					
Landfill	5	5	5	**5.00**	
Sorting_Equipment	4	5	4	**4.33**	
Facility Sector Asset					
Recreational and Cultural Facility					
Park	5	4	5	**4.67**	
Library	5	4	5	**4.67**	

Table F-5 ANOVA two-factor without replication test for knowledge representation clarity

Anova: Two-Factor Without Replication						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Rows	5.986111111	23	0.2602657	2.677018634	0.002216309	1.766805319
Columns	0.194444444	2	0.097222222	1	0.375735015	3.199581706
Error	4.472222222	46	0.097222222			
Total	10.65277778	71				

F.1.3.4 Completeness of the Knowledge Represented in the Tangible Capital Asset Ontology

The TCA_Onto was also evaluated for completeness. The completeness of the ontology was assessed in terms of the incompleteness in the knowledge representation. To assess incompleteness, a set of key concepts (TCAs) in the transportation, water, wastewater, solidwaste management, and facility sector was identified and presented to the respondents through the questionnaire. The respondents were asked to furnish their agreement on a scale of 1 (strongly disagree) to 5 (strongly agree) that the given concepts are the key concepts in the TCA_Onto. Also, the respondents were asked to identify and incorporate the concepts (TCAs) that they think are the key concepts and were missed out in the knowledge representation by the researcher. The respondents have recorded their agreement on the concepts presented in Table F-6. An average score was calculated, which ranged from 4 (agree) to 5 (strongly agree). The results of the survey indicate that the respondents were in general agreement on the completeness of the TCA_Onto.

The results were also analyzed for statistical significance using ANOVA two-factor without replication technique. In the analysis, an alpha value of 0.05 (95%) was used. The results of the statistical analysis are shown in Table F-7. The results show that the value of "F" is less than "F_{cri}" ($0.45<3.14$) and the value of $p>0.05$ ($0.64>0.05$), which means there is no significant difference between the responses and the null hypothesis is to be accepted. The results indicate that the respondents were in general agreement on the completeness of knowledge represented in the TCA_Onto.

Table F-6 Completeness of the knowledge represented in the tangible capital asset ontology

Knowledge Representation (Ontology) Completeness					
Key Concepts Tangible Capital Asset	**Respondents**			**Average Score**	**Legends**
	A	**B**	**C**		
	Agreement Rating				
Infrastructure Sector Asset					0 Unable to Rate
Transportation Sector Asset					
Road	5	5	5	**5.00**	
Bridge	5	5	5	**5.00**	1Strongly Disagree
Tunnel	4	4	5	**4.33**	
Pathway	5	5	5	**5.00**	
Wall	5	5	5	**5.00**	2 Disagree
Shoulder	4	5	5	**4.67**	
Curb	5	4	5	**4.67**	
Road_Right_of_Way	5	5	5	**5.00**	3 Neither Agree
Traffic_Signal and Traffic_Sign	5	5	4	**4.67**	nor Disagree
Transit_Train and Transit_Bus	4	4	4	**4.00**	
Water Sector Asset					
Water_Line	5	5	5	**5.00**	4 Agree
Well	5	5	5	**5.00**	
Tank	5	4	5	**4.67**	
Reservoir	5	4	5	**4.67**	5 Strongly Agree
Valve	5	5	5	**5.00**	
Pump	5	5	5	**5.00**	
Meter	5	5	5	**5.00**	
Wastewater Sector Asset					
Sanitary_Wastewater_Line	5	5	5	**5.00**	
Storm_Wastewater_Line	5	5	5	**5.00**	
Manhole	5	5	5	**5.00**	
Pond	4	5	4	**4.33**	
Dyke	4	5	5	**4.67**	
Culvert	5	5	5	**5.00**	
Dam	5	5	5	**5.00**	
Solidwaste Sector Asset					
Landfill	5	5	4	**4.67**	
Sorting_Equipment	5	5	4	**4.67**	
Waste-Disposal_Vehicle	5	4	4	**4.33**	
Facility Sector Asset					
Recreational and Cultural Facility					
Heritage_Facility	5	5	4	**4.67**	
Museum	5	5	5	**5.00**	
Art_Gallery	5	5	5	**5.00**	
Protective Service Facility					
Building_Fire_Protection (Fire_Station)	4	5	5	**4.67**	
Vehicle_Fire_Protection (Fire_Truck)	5	4	4	**4.33**	
Equipment_Fire_Protection	5	4	4	**4.33**	

Table F-7 ANOVA two-factor without replication test for knowledge representation completeness

	Anova: Two-Factor Without Replication					
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Rows	7.65656566	32	0.23926768	1.55327869	0.06749314	1.62386203
Columns	0.14141414	2	0.07070707	0.45901639	0.63396888	3.14043762
Error	9.85858586	64	0.1540404			
Total	17.6565657	98				

F.1.3.5 Correctness of the Knowledge Represented in the Tangible Capital Asset Ontology

The TCA knowledge represented in the TCA_Onto was assessed for correction as part of the evaluation. A set of concepts (TCAs) was identified in the facility and four infrastructure sectors; transportation, water, wastewater, and solidwaste management that was presented to the respondents through a structured questionnaire. The respondents were requested to assess these concepts on a scale of 1 (strongly disagree) to 5 (strongly agree). Each concept was assessed as shown in Table F-8 and an average score was calculated. The average score of all the concepts represented in Table F-8 ranged from 4 (agree) to 5 (strongly agree), indicating that the respondents were in full agreement on the correctness of the knowledge represented in the TCA_Onto.

The results were further tested for statistical significance using ANOVA two-factor without replication technique. The null hypothesis states that there is not statistical significance between the responses of the three respondents. For the analysis, a "p" value of 0.05 or confidence level of 95% was used. The results of the statistical analysis are reflected in Table F-9, showing that the value of "F" is less than "F_{cri}" (2.67<3.17) and "p" is greater than 0.05 (0.07>0.05). The results indicate that the null hypothesis is to be accepted and that there is no significant difference between the responses of the three respondents. This means that the respondents were in general agreement on the correctness of the knowledge represented in the TCA_Onto.

Table F-8 Correctness of the knowledge represented in the tangible capital asset ontology

Knowledge Representation (Ontology) Correctness					
Concepts **Tangible Capital Assets**	**Respondents**			**Average Score**	**Legends**
	A	**B**	**C**		
	Agreement Rating				
Infrastructure Sector Asset					0 Unable to Rate
Transportation Sector Asset					
Asphalt_Road	5	5	5	**5.00**	
Two_Lane_Road	5	5	5	**5.00**	1 Strongly Disagree
Asphalt_Shoulder	5	5	4	**4.67**	
Concrete_Median	5	4	5	**4.67**	
Masonary_Guard_Rail	4	4	4	**4.00**	2 Disagree
Single_Tube_Tunnel	4	4	4	**4.00**	
Suspension_Bridge	5	5	5	**5.00**	
Concrete_Bridge	5	5	5	**5.00**	3 Neither Agree
Transfer_Station	3	5	5	**4.33**	nor Disagree
Traffic_Camera	4	5	5	**4.67**	
Water Sector Asset					
Mainline_Water	5	5	4	**4.67**	4 Agree
Cement_Water_Line	5	5	3	**4.33**	
Tank	5	5	4	**4.67**	
Filteration_Facility_Water	4	5	5	**4.67**	5 Strongly Agree
Wastewater Sector Asset					
Mainline_Sanitary_Wastewater	5	5	4	**4.67**	
Treatment_Facility	5	5	5	**5.00**	
Serviceline_Storm_Wastewater	5	5	3	**4.33**	
Slab_Culvert	5	4	5	**4.67**	
Pond	4	5	5	**4.67**	
Solidwaste Sector Asset					
Landfill	5	5	5	**5.00**	
Sorting_Facility	5	5	4	**4.67**	
Facility Sector Asset					
Recreational and Cultural Facility					
Museum_Facility	5	4	4	**4.33**	
Library_Facility	5	4	5	**4.67**	
Senior_Center_Facility	5	5	4	**4.67**	
Protective Services Facility					
Building_Police_Protection (Police_Station)	5	5	5	**5.00**	
Vehicle_Police_Protection (Police_Car)	5	4	4	**4.33**	
Equipment_Police_Protection	5	4	3	**4.00**	

Table F-9 ANOVA two-factor without replication test for knowledge representation correctness

	Anova: Two-Factor Without Replication					
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	7.80246914	26	0.30009497	0.89014085	0.61796347	1.7096195
Columns	1.80246914	2	0.90123457	2.67323944	0.07850752	3.17514097
Error	17.5308642	52	0.337132			
Total	27.1358025	80				

F.1.3.6 Overall Assessment of the Knowledge Represented in the Tangible Capital Asset Ontology

Finally, the respondents were asked to carry out an overall assessment of the TCA_Onto in terms of the clarity, completeness, and correctness on a scale of 1 to 5. Each respondent rated the TCA_Onto and their assessment is presented in Table F-10. An average score of 4.67 was calculated indicating that the respondents are in universal agreement on the clarity, completeness, and correctness of the knowledge represented in the TCA_Onto.

Table F-10 Tangible capital asset ontology overall assessment

<table>
<tr><th colspan="6">Knowledge Representation (Ontology) Validation Overall Assessment</th></tr>
<tr><th rowspan="3">Overall Assessment</th><th colspan="3">Respondents</th><th rowspan="3">Average Score</th><th rowspan="3">Legends</th></tr>
<tr><th>A</th><th>B</th><th>C</th></tr>
<tr><th colspan="3">Agreement Rating</th></tr>
<tr><td>Does the ontology provide a clear, complete, and correct representation of the tangible capital assets in the area of infrastructure management?</td><td>5</td><td>5</td><td>4</td><td>4.67</td><td>0 Unable to Rate
1 Strongly Disagree
2 Disagree
3 Neither Agree nor Disagree
4 Agree
5 Strongly Agree</td></tr>
</table>

The University of
British Columbia

Appendix G Transaction Domain Ontology Validation Questionnaire

Expert Review Survey Towards Transaction Domain Ontology Validation

RESEARCH BACKGROUND INFORMATION, OBJECTIVES,

RESPONDENT CONSENT INFORMATION

&

QUESTIONNAIRE

Investigators:

Thomas Froese—Professor (Supervisor)

Jehan Zeb—Ph.D. Candidate (Investigator)

Ontology Evaluation

Expert Review Survey Towards Transaction Domain Ontology Validation

Introduction

More than most other industries, the Architectural, Engineering, Construction, and Facility Management (AEC/FM) industry is inherently fragmented and multi-disciplinary. Various AEC/FM organizations join hands to accomplish projects in a collaborative manner. As part of the collaborative effort, large volumes of information created at source are required to be exchanged between the parties due to information dependency. As information systems continue to evolve, these information exchanges will increasingly involve data exchanges between different stakeholders' computer applications. An unresolved challenge facing government agencies, contractor organization, consulting firms, architects, private and public associations, and private agencies in the AEC/FM industry, is the issue of how best to carry out and manage these electronic information exchanges.

Presently, information is exchanged between collaborating partners in manual, unstructured and ad hoc ways, which contribute towards ineffective and poor communication in the AEC/FM industry. It leads to time and cost overrun productivity losses, rework, and reduced quality. Emerging trends in the AEC/FM industry for globalization and partnering combined with enhanced pressure to reduce project time and cost require the effective and efficient exchange of information. It emphasizes the need to structure information and formalize information flows to enable electronic communication between partners and ensure consistent and timely exchange of information. This leads to the creation of the core research question "how to structure information and formalize information flows".

Some of the reasons for communication non-formalism and ad-hocism include a variety of the AEC/FM processes conducted differently in various parts of the globe; numerous diversified stakeholders need different exchange requirements in different contexts, and non-availability of the most relevant transaction formalism methodology. It emphasizes the need to develop a methodology or protocol to formalize workflows and message templates for computer-based exchange of information. This would transform current practice of manual (ad hoc and informal) data exchange to a more formalized computer-to-compute (formal and structured) based exchange of information

For computers to talk to each other, information relating AEC/FM processes and messages should be represented in a computer interpretable format—the ontology. The ontology represents the knowledge of a specific domain that is based on shared and common understanding of the industry. Two ontologies have been developed as part of this research work, the transaction domain ontology (Trans_Dom_Onto) and transaction application ontology for message construction. The Trans_Dom_Onto represents knowledge to support the design, implementation, and management of transactions in the domain of infrastructure management. The application ontology, termed as tangible capital asset ontology (TAC_Onto), represents knowledge related to tangible capital assets to support the design of message templates for asset inventory and condition assessment reporting between different municipalities and the provincial government. This survey is conducted to validate the knowledge represented in the Trans_Dom_Onto.

Research Goal

The main research goal is to develop a methodology or protocol to formalize communication processes and message templates in the domain of infrastructure management to transform current practice of manual data exchange to a more formalized computer-to-computer based exchange of information.

Research Objectives

Develop a protocol for the design and management of information flows in the domain of infrastructure management.

i. Develop a protocol to formalize transactions in the area of infrastructure management.

ii. Build transaction domain ontology to support the design and management of transaction maps and message templates in the domain of infrastructure management.

iii. Develop a tangible capital asset ontology, as an extension to the infrastructure product ontology, to support the design of message templates for asset inventory and condition assessment reporting.

iv. Demonstrate and test/evaluate the proposed approach through developing a prototype Asset Information Integrator System that uses the formalized transactions.

Purpose of the Ontology Validation Survey

The key purpose of the ontology validation survey is to validate the content of the Trans_Dom_Onto through experts in the domain of infrastructure management to check that a right ontology is built representing a real world model of the domain of interest.

Description of the Survey

Title: Expert Review Survey Towards Transaction Domain Ontology Validation

Supervisor: Professor, Thomas Froese

Department of Civil Engineering, (UBC)

2002-6250 Applied Science Lane,

Vancouver, BC, V6T 1Z4.

Investigator and Interviewer: Jehan Zeb, Graduate Research Assistant

Department of Civil Engineering, (UBC)

2002-6250 Applied Science Lane

Vancouver, BC, V6T 1Z4

Role of Respondents

Respondents are expected to have experience in one of the infrastructure sectors (transportation, water, wastewater, solid waste management), and/or communication or knowledge management. As a respondent, you are required to participate in all three sessions of the interview; (i) introduction (25-30 minutes), (ii) comprehension/navigation (25-30 minutes), and (iii) execution (50-60 minutes). In the introduction session, various concepts of ontology engineering will be introduced. In the comprehension session, experts will understand the whole transaction knowledge represented in the Trans_Dom_Onto while navigating through A4 size drawings developed in the Unified Modeling Language (UML). During the execution session, respondents are required to answer questions contained in section 1 through 6 of the questionnaire. The whole interview process is expected to be completed within 2 hours.

Use of Information, and Procedures adopted for Data Confidentiality

All the questions reflected in the questionnaire are optional. The results of the data collected will be presented in the form of an ontology assessment report, which will be made public in the future. Please do not provide any information that you think is confidential or of a sensitive nature for yourself and your organization. The information provided will only be used to achieve objectives of this research work only. Please inform us if you do not wish us to publish your name or that of your organization.

Questions and Additional Information

A structured questionnaire will be used to collect information from experts during a face-to-face interview. Most of the questions will be dealt with during the interview. However, any question or additional information can be asked from the supervisor or investigator at the above-mentioned addresses.

Risks and its Remedial Measures

Researchers anticipate none of the risks for this research work, such as, breach of confidentiality, social stigmatization, threats to reputation, and psychological harm. However, it is requested not to provide any information that you deem is confidential or of a sensitive nature. As a respondent, you will receive a copy of the final ontology assessment report.

Respondents' Rights

You are free to decline to participate in this research upon invitation, withdraw from the study at any time with no consequences, and withhold any information that you do not wish to provide. If you have any concerns about your treatment of rights as a research respondent, you may call the Research Subject Information Line at (604) 822 8598, located in the UBC Office of Research Services at the University of British Columbia.

Potential Conflicts of Interest

This study relates to ontology validation that is part of the ongoing research work at the University of British Columbia. Therefore, no conflict of interest is anticipated for this research work.

Questionnaire

The questionnaire is to be presented to the respondents during the execution session of the interview. The questionnaire is divided into following six sections comprising:

Section—1: Respondent profile information

Section—2: Familiarity with the infrastructure sectors and data modeling

Section—3: Knowledge representation (ontology) clarity

Section—4: Knowledge representation (ontology) completeness

Section—5: Knowledge representation (ontology) correctness

Section—6: Knowledge representation (ontology) overall assessment

QUESTIONNAIRE

Definitions of the words in the questionnaire with bold, italic, and underline are defined in the glossary of terms at the end of this document.

Section 1: Respondent Profile Information

This section captures the general and technical profile information of the respondents.

Please fill out the following respondent profile information in Table 1-1.

S. No.	Table 1-1 Information relating Respondent Profile	
A.	**Respondent General Profile**	
1	Respondent Name	
2	Respondent Position/Designation/Title	
3	Respondent Organization Name	
4	Respondent Tel No.	
5	Respondent E-mail Address	
B.	**Respondent Technical Profile**	
6	Years of Experience	
7	Field/Sector of Experience	

☐ Please check if you would like us to withhold your name and that of your organization from publication.

Date interview survey conducted: **/dd** **/MM** **/YYYY**

Section 2: Familiarity with Infrastructure Sectors and ***<u>Data Modeling</u>***

2.1 What is your level of familiarity with the following infrastructure sectors? Please select one familiarity level for each infrastructure sector in Table 2-1.

Table 2-1 Familiarity with Infrastructure Sector

	Familiarity Level					
	Unable to Rate	Not at all Familiar	Slightly Familiar	Somewhat Familiar	Moderately Familiar	Extremely Familiar
Infrastructure Sectors	0	1	2	3	4	5
Transportation						
Water						
Wastewater						
Solidwaste Management						

2.2 What is your level of familiarity with ***<u>data or information modeling</u>***? Please select one familiarity level in Table 2-2.

Table 2-2 Familiarity with Data or Information Modeling

Unable to Rate	Not at all Familiar	Slightly Familiar	Somewhat Familiar	Moderately Familiar	Extremely Familiar
0	1	2	3	4	5

2.3 What is your level of familiarity with formalizing technical communications or information exchange? (e.g. for IT development, contract requirements, etc.). Please select one familiarity level in Table 2-3.

Table 2-3 Familiarity with Formalizing Technical Communication

Unable to Rate	Not at all Familiar	Slightly Familiar	Somewhat Familiar	Moderately Familiar	Extremely Familiar
0	1	2	3	4	5

Section 3: Knowledge Representation (*Ontology*) Clarity

3.1 Does the ontology clearly define and effectively communicate the intended meanings of the transaction concepts? OR Is the knowledge captured in the ontology understandable? Please select one of the choices for each concept shown in Table 3-1.

NOTE: Parent classes of each concept are listed in the last column of Table 3-1 for convenience.

Table 3-1 Knowledge Representation (Ontology) Clarity

Concepts	Agreement Level: Unable to Rate	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree	List of the Parent-classes
	0	1	2	3	4	5	Parent classes------------to ------------Children classes
Transaction							
Publically_Accessible_Transaction							Transaction→Communication_Transaction→Control_Transaction→ Accesibility_Based_Transaction→**Publically_Accessible_Transaction**
One_Action_WithAcknowledgement_ Transaction							Transaction→Communication_Transaction→Pattern_Transaction→ **One_Action_WithAcknowledgement_Transaction**
Owner_Architect_Transaction							Transaction→Domain_Transaction→Collaboration_Based_Transaction→Bilateral_Transaction→Owner_Related_Transaction→**Owner_Architect_Transaction**
Transportation_Sector_Transaction							Transaction→Domain_Transaction→Sector_Transaction→ **Transportation_Sector_Transaction**
Actor Role							
Consultant_Role							Actor_Role→Support_Role→Professional_Support_Role→**Consultant_Role**
Receiver_Role							Actor_Role→Transaction_Role→**Receiver_Role**

Table 3-1 Knowledge Representation (Ontology) Clarity							
	Agreement Level						
	Unable to Rate	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree	List of the Parent-classes
Concepts	**0**	**1**	**2**	**3**	**4**	**5**	**Parent classes------------to ------------Children classes**
Information							
Message_Body_Information							Information→Payload_Information→Message_Placement_Payload_ Information→**Message_Face/Body_Information**
Transaction_General_Information							Information→Header_Information→Service_Header_Information→ **Transaction_General_Information**
Message							
Acknowledgement_ Message							Message→Function_Message→Signal_Message→ **Acknowledgement_ Message**
Soft_Message							Message→Formulation_Message→Written_Message→**Soft_Message**
Channel							
E-mail_Channel							Mechanism→Method→Transaction_Communication_Channel→ erbal_Channel→Written_Channel→Electronic_Written_Channel→ Web_Based_Written_Channle→**E-mail_Channel**
Attribute							
Transaction_Duration_Attribute							Header_Information_Attribute→Temporal_Information_Attribute→ Duration_Attribute→**Transaction_Duration_Attribute**
Please list coments, and specific concerns, issues, or errors that you have noticed:							

Section 4: Knowledge Representation (*Ontology*) Completeness

4.1 Does the knowledge representation (ontology) cover the key concepts required for the design, implementation, and management of computer-to-computer communications among various infrastructure organizations? Please select one of the choices for each of the key concepts presented in Table 4-1.

Table 4-1 Knowledge Representation (Ontology) Completeness

	Agreement Level					
	Unable to Rate	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
Key Concepts	**0**	**1**	**2**	**3**	**4**	**5**
Transaction						
Actor						
Actor Role						
Information						
Message						
Channel						
Record other key concepts, if you deem them important						
Please list coments, and specific concerns, issues, or errors that you have noticed:						

Section 5: Knowledge Representation (*Ontology*) Correctness

5.1 Does the ontology correctly describe class definitions from a real world perspective? Please select one of the choices for each concept in Table 5-1.

NOTE: Parent classes of each concept are listed in the last column of Table 5-1 for convenience.

Table 5-1 Knowledge Representation (Ontology) Correctness

Concepts	Agreement Level: Unable to Rate 0	Strongly Disagree 1	Disagree 2	Neither Agree nor Disagree 3	Agree 4	Strongly Agree 5	List of the Parent classes: Parent classes------------to ------------Children classes
Transaction							
Automated Transaction							Transaction→Communication_Transaction→Actor_Role_Centered_ Transaction→Agent_Person_Transaction→Computer_To_Computer_ Transaction → **Automated_Transaction**
Web_Transaction							Transaction→Communication_Transaction→Channel_Transaction→ **Web_Transaction**
Owner_GC_Consultant_ Transaction							Transaction→Domain_Transaction→Collaboration_Based_Transaction→ Multilateral_Transaction→**Owner_GC_Consultant_Transaction**
Water_Sector_Transaction							Transaction→Domain_Transaction→Sectoral_Transaction→ **Water_Sector_ Transaction**
Actor Role							
Local_Government_Role							Actor_Role→Government_Role→**Local_Government_Role**
Sender_Role							Actor_Role→Transaction_Role→**Sender_Role**

Table 5-1 Knowledge Representation (Ontology) Correctness							
	Agreement Level						
	Unable to Rate	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree	List of the Parent classes
Concepts	**0**	**1**	**2**	**3**	**4**	**5**	**Parent classes------------to ------------Children classes**
Information							
Design_Report_Information							Information→Payload_Information→Formulation_Paylod_Information→ Document_Information→Design_Information→**Design_Report_Information**
Temporal_Information							Information→Header_Information→Delivery_Header_Information→ **Temporal_Information**
Message							
Receipt_Acknowledgement _Message							Message→Function_Message→Signal_Message→Acknowledgement_ Message→Positive_Acknowledgement_Message→ **Receipt_Acknowledgement_Message**
Fully_Structured_Message							Message→Representation_Message→**Fully_Structured_Message**
Channel							
Server_Based_Channel							Mechanism→Method→Transaction_Communication_Channel→ Verbal_Channle→Written_Channel→Electronic_Written_Channel→ Web_Based_Written_Channel→**Server_Based_Channel**
Attribute							
Transmission_Cost_ Attribute							Transaction_Attribute→Transaction_Cost_Attribute→Variable_Cost_ Attribute→**Transmission_Cost_Attribute**

Table 5-1 Knowledge Representation (Ontology) Correctness							
	Agreement Level						
	Unable to Rate	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree	List of the Parent classes
Concepts	**0**	**1**	**2**	**3**	**4**	**5**	**Parent classes------------to ------------Children classes**
Constraint							
Transaction_Design_ Requirement_Constraint							Constraint→Internal_Constraint→User_Requirement_Constraint→ **Transaction_Design_Requirement_Constraint**
Relationship							
exchangedIn							Relationship→Directed_Association_Relationship→Communicate→ **exchangedIn**
Please list coments, and specific concerns, issues, or errors that you have noticed:							

Section 6: Knowledge Representation (*Ontology*) Overall Assessment

6.1 Please record your overall assessment in Table 6-1. Please select one of the choices shown in Table 6-1.

Table 6-1 Knowledge Representation (Ontology) Validation Overall Assessment

	Agreement Level						
	Unable to Rate	Strongly Disagree	Disagree	Neither Agree Nor Disagree	Agree	Strongly Agree	
Overall Assessment	0	1	2	3	4	5	
Does the ontology provide a clear, correct, and complete representation of the transaction knowledge in the area of infrastructure management?							
Please list coments, and specific concerns, issues, or errors that you have noticed:							

Expert Review Survey Towards Transaction Domain Ontology Validation

Glossary of Items

1. Actor Role

Actor role is defined as "a set of connected behaviors and attributes as conceptualized by actors in a given social position. **OR** it refers to the responsibilities (of a designer, contractor, director etc.) that various actors (organizations and individuals) carry out in a given process or context.

2. Actor

The actor is either organization or individual, who occupies distinct positions and resume certain roles and responsibilities in a given process or context.

3. Attribute

Attribute is a characteristic that describes a thing, entity, or concept.

4. Channel

The transaction channel is defined as the medium through which information is conveyed between the transaction roles (the sender and receiver roles).

5. Data Modeling

Data modeling is the process of identifying entities, the relationship between those entities and their attributes. Data modeling is a method used to define and analyze data requirements needed to support the business processes of an organization.

6. Information

Information is defined as "data referenced and utilized during the process of creating and sustaining the built environment". **OR** Information is data (refers to a series of atomic and disconnected facts, statement of event or observation), processed, analyzed and co-related to a context to make it useful for the user.

7. Message

The message refers to the information formulated in tangible (written) and intangible (verbal and non-verbal) forms that is exchanged between the collaborating parties.

8. Ontology Validation

Ontology validation refers to judging the content of the ontology from a real world perspective, to ensure that the ontological model accurately captures real world model of the domain of interest.

9. Ontology

The ontology is defined as an explicit and formal specification of a conceptualization.

10. Transaction

Any exchange of information, communication, or interaction between different parties that make up the information flow can be described as a transaction. **OR** It is a pattern of activities that is performed by two actors: the initiator and the executer.

The University of
British Columbia

Appendix H TCA Ontology Validation Questionnaire

Expert Review Survey Towards Tangible Capital Asset Ontology Validation

RESEARCH BACKGROUND INFORMATION, OBJECTIVES,

RESPONDENT CONSENT INFORMATION

&

QUESTIONNAIRE

Investigators:

Thomas Froese—Professor (Supervisor)
Jehan Zeb—Ph.D. Candidate (Investigator)

Ontology Evaluation

Expert Review Survey Towards Tangible Capital Asset Ontology Validation

Introduction

Municipalities own, operate, and manage diversified Tangible Capital Assets (TCA) to provide services to their citizens, and they use either computer or paper-based information systems to manage these assets. These information systems generate large amounts of asset data that are exchanged between different departments of a municipality and between a municipality and other agencies to manage these large and complex infrastructure systems. The growing trend is to automate or semi-automate these data exchanges (referred to as transactions), which requires transactions to be formalized and message templates to be explicitly defined. Examples of transactions or data exchanges are: asset inventory and condition assessment reporting, exchange of data regarding buried infrastructure, and data exchange between different parties as part of disaster management. Transaction and message template formalism is addressed through the development of an ontology-supported Transaction Formalism Protocol (TFP). The protocol is a step-by-step procedure that transaction development personnel can use to efficiently formalize transactions, and the ontology supports this by explicitly defining the terms and concepts used to formalize transactions and message templates.

Currently, there are issues hampering the design of message templates for TCA reporting, including; (i) heterogeneity - every municipality records and manages asset data in a different data format; (ii) lack of uniformity – no consistency in the definitions of various classes of the TCA; and (iii) lack of aggregation – lack of infrastructure component-based aggregation of the TCA data (Felio, 2012); and (iv) paper-based management of TCA data. These issues make it difficult to collect and compile asset data received from different city, regional, town, district, and village municipalities for financial need analysis. Financial analysis is conducted at the provincial, regional, and/or federal level to assess financial needs and allocate funds to various municipalities based on the condition of the assets under different investment programs.

To address these issues, a Tangible Capital Asset Ontology (TCA_Onto) is developed as an extension to a previously developed Infrastructure Product Ontology (IPD-Onto). According to Gruber (1995), an ontology is an “explicit formal specification of the terms in the domain and the relations among them." The TCA_Onto represents the TCAs in the facility and four infrastructure sectors: transportation, water, wastewater, and solid waste management. The TCA_Onto formally defines the TCA classes that are to be used as payload information while creating message templates for the asset inventory and condition assessment reporting/tangible capital asset reporting between different municipalities and the provincial government. These formalized message templates are to be implemented in a prototype system – an asset information integrator system (AIIS) to be developed at the provincial level as part of this research work. This survey is planned to validate the knowledge represented in the TCA_Onto, specifically with regards to the TCAs in the four infrastructure management sectors: transportation, water, wastewater, and solid waste management.

Research Goal

The main goal of this research work is to develop an ontology-supported methodology to formalize transactions and message templates in the domain of infrastructure management effectively and efficiently. This would transform current practice of manual exchange to a more formalized computer-to-computer based exchange of information.

Overall Research Objectives

Following are the three core objectives of the overall research work.

i. Devise a step-be-step procedure to define transactions and message templates for computer based exchange of information.

ii. Develop the Trans_Dom_Onto for the design and management of transactions in infrastructure management.

iii. Develop the TCA_Onto for the design of message templates for the asset inventory and condition assessment reporting/tangible capital asset reporting process.

Purpose of the Ontology Validation Survey

The key purpose of the ontology validation survey is to validate the content of the TCA_Onto through experts in the domain of infrastructure management. The ontology validation ensures that a right ontology is built from a real-world perspective in the domain of infrastructure management.

Description of the Survey

Title: Expert Review Survey Towards Tangible Capital Asset Ontology Validation

Supervisor: Professor, Thomas Froese

Department of Civil Engineering, (UBC)

2002-6250 Applied Science Lane, Vancouver, BC, V6T 1Z4

Investigator and Interviewer: Jehan Zeb, Ph. D. Candidate

Department of Civil Engineering, (UBC)

2002-6250 Applied Science Lane, Vancouver, BC, V6T 1Z4

Role of Respondents

Respondent is expected to have experience in one of the infrastructure sectors: transportation, water, wastewater, and solid waste management; and/or tangible capital asset reporting, data modeling or knowledge management, and tangible capital asset reporting. As a respondent, you are required to attend all three sessions of the interview; (i) introduction (25-30 minutes), (ii) comprehension/navigation (25-30 minutes), and (iii) execution (50-60 minutes). In the introduction session, concept of ontology engineering is to be introduced. In the comprehension session, experts will understand the entire TCA knowledge represented in the TCA_Onto while navigating through A4 size drawings developed in the Unified Modeling Language (UML). During the execution session, respondents are required to answer questions contained in section 1 through 6 of the questionnaire. The whole interview process is expected to be completed within 2 hours.

Use of Information, and Procedures Adopted for Data Confidentiality

All the questions shown in the questionnaire are optional. The results of the data collected will be presented in the form of an ontology assessment report, which will be made public in the future. Please do not provide information that you think is confidential or of a sensitive nature. The information provided will be used only for this research work. Please inform us if you do not wish us to publish your name or that of your organization.

Questions and Additional Information

A structured questionnaire will be used to collect information from the experts during a face-to-face interview; therefore, most of the questions will be dealt-with during the interview. However, any question or additional information can be asked from the supervisor and investigator at the above-mentioned addresses.

Risks and its Remedial Measures

The researchers anticipate none of the risks, such as, breach of confidentiality, social stigmatization, threats to reputation, and psychological harm, for this research. However, it is requested not to provide any information that you consider confidential or of a sensitive nature. As a respondent, you will receive the ontology assessment report.

Respondents' Rights

You are free to decline to participate in this research upon invitation, withdraw from the study at any time with no consequences, and withhold any information that you do not wish to provide. If you have any concerns about your treatment of rights as a research respondent, you may call the Research Subject Information Line at (604) 822 8598, located in the UBC Office of Research Services at the University of British Columbia.

Potential Conflicts of Interest

This study relates to ontology validation that is part of the ongoing research work; as such, researchers anticipate no conflict of interest between you or your organization and researcher.

Questionnaire

The questionnaire is to be presented to the respondents during the execution session of the interview. The questionnaire is divided into following six sections comprising:

Section—1: Respondent profile information

Section—2: Familiarity with the infrastructure sectors and data modeling, and PSAB-3150 reporting requirements

Section—3: Knowledge representation (ontology) clarity

Section—4: Knowledge representation (ontology) completeness

Section—5: Knowledge representation (ontology) correctness

Section—6: Knowledge representation (ontology) overall assessment

QUESTIONNAIRE

Definitions of the words in the questionnaire with bold, italic, and underline are defined in the glossary of terms at the end of this document.

Section 1: Respondent Profile Information

This section shows general and technical profile information of the respondents.

Please fill out the following information in Table 1-1.

S. No.	Table 1-1 Information relating Respondent Profile	
A.	**Respondent General Profile**	
1	Respondent Name	
2	Respondent Position/Designation/Title	
3	Respondent Organization Name	
4	Respondent Tel No.	
5	Respondent E-mail Address	
B.	**Respondent Technical Profile**	
6	Years of Experience	
7	Field/Sector of Experience	

☐ Please check if you would like us to withhold your name and that of your organization from publication.

Date interview survey conducted: **/dd /MM /YYYY**

Section 2: Familiarity with Infrastructure Sectors and ***Data Modeling***

2.1 What is your level of familiarity with the following infrastructure sectors? Please select one familiarity level for each infrastructure sector in Table 2-1.

Table 2-1 Familiarity with Infrastructure Sector						
	Familiarity Level					
	Unable to Rate	Not at all Familiar	Slightly Familiar	Somewhat Familiar	Moderately Familiar	Extremely Familiar
Infrastructure Sectors	0	1	2	3	4	5
Transportation						
Water						
Wastewater						
Solidwaste Management						

2.2 What is your level of familiarity with the ***data or information modeling?*** Please select one familiarity level Table 2-2.

Table 2-2 Familiarity with Data or Information Modeling					
Unable to Rate	Not at all Familiar	Slightly Familiar	Somewhat Familiar	Moderately Familiar	Extremely Familiar
0	1	2	3	4	5

2.3 What is your level of familiarity with the Public Sector Accounting Board (PSAB-3150) reporting requirements for the ***tangible capital assets***? Please select one familiarity level in Table 2-3.

Table 2-3 Familiarity with Public Sector Accounting Board Accounting Reporting Requirements					
Unable to Rate	Not at all Familiar	Slightly Familiar	Somewhat Familiar	Moderately Familiar	Extremely Familiar
0	1	2	3	4	5

Section 3: Knowledge Representation (*TCA_Ontology*) Clarity

3.1 Does the ontology clearly defines and effectively communicate the intended meanings of the concepts in terms of the ***tangible capital assets***? OR Is the knowledge captured in the ontology understandable? Please select one of the choices for each of the concepts shown in Table 3-1.

NOTE: Parent classes of each of the TCA are listed in the last column of Table 3-1 for convenience.

Table 3-1 Knowledge Representation (Ontology) Clarity

Concepts Tangible Capital Asset	Agreement Level: Unable to Rate	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree	List of the Parent classes
	0	1	2	3	4	5	Parent classes------------to ------------Children classes
Infrastructure Sector Asset							
Transaportation Sector Asset							
Urban_Freeway							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Transportation_Sector_Asset→Road_Transportation_Asset→Function_Based_Road→Urban_Road→**Urban_Freeway**
Rural_Freeway							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Transportation_Sector_Asset→Road_Transportation_Asset→Function_Based_Road→Rural_Road→**Rural_Freeway**
Urban_Collector_Road							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Transportation_Sector_Asset→Road_Transportation_Asset→Function_Based_Road→Urban_Road→**Urban_Collector_Road**
Rural_Collector_Road							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Transportation_Sector_Asset→Road_Transportation_Asset→Function_Based_Road→Rural_Road→**Rural_Collector_Road**

Table 3-1 Knowledge Representation (Ontology) Clarity							
	Agreement Level						
	Unable to Rate	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree	List of the Parent classes
Concepts **Tangible Capital Asset**	0	1	2	3	4	5	Parent classes------------to ------------Children classes
Infrastructure Sector Asset							
Transaportation Sector Asset							
Urban_Local_Road							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Transportation_Sector_Asset→Road_Transportation_Asset→Function_Based_Road→Urban_Road→**Urban_Local_Road**
Rural_Local_Road							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Transportation_Sector_Asset→Road_Transportation_Asset→Function_Based_Road→Rural_Road→**Rural_Local_Road**
Alley_Pathway							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Transportation_Sector_Asset→Pathway_Transportation_Asset→**Alley_Pathway**
Twin_Tube_Tunnel							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Transportation_Sector_Asset→Tunnel_Transportation_Asset→**Twin_Tube_Tunnel**
Retaining_Wall							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Transportation_Sector_Asset→Wall_Transportation_Asset→**Retaining_Wall**
Transit_Train							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Transportation_Sector_Asset→Vehicle_Transportation_Asset→**Transit_Train**
Traffic_Signal							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Transportation_Sector_Asset→Machinery_&_Equipment_Transportation_Asset→Regulatory_Equipment→**Traffic_Signal**

Table 3-1 Knowledge Representation (Ontology) Clarity							
	Agreement Level						
	Unable to Rate	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree	List of the Parent classes
Concepts **Tangible Capital Asset**	0	1	2	3	4	5	Parent classes------------to ------------Children classes
Infrastructure Sector Asset							
Water Sector Asset							
Water_Line							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Water_Sector_Asset→**Water_Line**
Tank							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Water_Sector_Asset→**Tank**
Reservoir							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Water_Sector_Asset→**Reservoir**
Meter							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Water_Sector_Asset→Machinery_&_Equipment_Water_**Meter**

Table 3-1 Knowledge Representation (Ontology) Clarity							
	Agreement Level						
	Unable to Rate	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree	List of the Parent classes
Concepts **Tangible Capital Asset**	0	1	2	3	4	5	Parent classes------------to ------------Children classes
Infrastructure Sector Asset							
Wastewater Sector Asset							
Sanitary_Wastewater_Line							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Wasterwater_Sector_Asset→Sanitary_Wasetwater_Asset→**Sanitary_Wastewater_Line**
Storm_Wastewater_Line							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Wasterwater_Sector_Asset→Storm_Wasetwater_Asset→**Storm_Wastewater_Line**
Manhole							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Wasterwater_Sector_Asset→Sanitary_Wasetwater_Asset→**Manhole**
Culvert							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Wasterwater_Sector_Asset→Storm_Wasetwater_Asset→**Culvert**
Pump							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Wasterwater_Sector_Asset→Sanitary_Wasetwater_Asset→Machinery_&_Equipment_Wastewater_Asset_**Pump**
Solidwaste Management							
Landfill							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Solidwaste_Sector_Asset→Land_Solidwaste_**Landfill**
Sorting_Equipment							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Solidwaste_Sector_Asset→Machinery_&_Equipment_Solidwaste→ **Sorting_Equipment**

Table 3-1 Knowledge Representation (Ontology) Clarity							
	Agreement Level						
	Unable to Rate	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree	List of the Parent classes
Concepts **Tangible Capital Asset**	0	1	2	3	4	5	Parent classes------------to ------------Children classes
Facility Sector Asset							
Recreational and Cultural Facility							
Park							Tangible_Capital_Asset→Sector_Based_Asset→Facility_Sector_Asset→Recreational_&_Cultural_Facility→**Park**
Library							Tangible_Capital_Asset→Sector_Based_Asset→Facility_Sector_Asset→Recreational_&_Cultural_Facility→**Library**
Please list coments, and specific concerns, issues, or errors that you have noticed:							

Section 4: Knowledge Representation (***Ontology***) Completeness

4.1 Does the knowledge representation (TCA_Onto) cover the relevant key ***tangible capital assets*** required for the asset inventory and condition assessment reporting in line with PSAB-3150 reporting requirements? Please select one of the choices for each of the key TCAs presented in Table 4-1.

Table 4-1 Knowledge Representation (Ontology) Completeness

Key Concepts / Tangible Capital Asset	Agreement Level: Unable to Rate	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
	0	1	2	3	4	5
Infrastructure Sector Asset						
Transportation Sector Asset						
Road						
Bridge						
Tunnel						
Pathway						
Wall						
Shoulder						
Curb						
Road_Right_of_Way						
Traffic_Signal and Traffic_Sign						
Transit_Train and Transit_Bus						
Water Sector Asset						
Water_Line						
Well						
Tank						
Reservoir						
Valve						
Pump						
Meter						

Table 4-1 Knowledge Representation (Ontology) Completeness						
	Agreement Level					
	Unable to Rate	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
Key Concepts Tangible Capital Asset	0	1	2	3	4	5
Infrastructure Sector Asset						
Wastewater Sector Asset						
Sanitary_Wastewater_Line						
Storm_Wastewater_Line						
Manhole						
Pond						
Dyke						
Culvert						
Dam						
Solidwaste Sector Asset						
Landfill						
Sorting_Equipment						
Waste-Disposal_Vehicle						
Facility Sector Asset						
Recreational and Cultural Facility						
Heritage_Facility						
Museum						
Art_Gallery						
Protective Service Facility						
Building_Fire_Protection (Fire_Station)						
Vehicle_Fire_Protection (Fire_Truck)						
Equipment_Fire_Protection						
Please list coments, and specific concerns, issues, or errors that you have noticed:						

Section 5: Knowledge Representation (*Ontology*) Correctness

5.1 Does the ontology correctly describe class definitions from a real world perspective? Please select one of the choices for each concept in Table 5-1.

NOTE: Parent classes of each concept are listed in the last column of Table 5-1 for convenience.

Table 5-1 Knowledge Representation (Ontology) Correctness

Concepts Tangible Capital Assets	Agreement Level Unable to Rate 0	Strongly Disagree 1	Disagree 2	Neither Agree nor Disagree 3	Agree 4	Strongly Agree 5	List of the Parent-classes Parent classes------------to ------------Children classes
Infrastructure Sector Asset							
Transportation Sector Asset							
Asphalt_Road							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Transportation_Sector_Asset→Road_Transportation_Asset→Surface_Based_Road→**Asphalt_Road**
Two_Lane_Road							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Transportation_Sector_Asset→Road_Transportation_Asset→Traffic_Volume_Based_Road→Divided_Road→**Two_Lane_Road**
Asphalt_Shoulder							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Transportation_Sector_Asset→Shoulder_Transportation_Asset→ **Asphalt_Shoulder**
Concrete_Median							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Transportation_Sector_Asset→Median_Transportation_Asset→**Concrete_Median**

Table 5-1 Knowledge Representation (Ontology) Correctness							
	Agreement Level						
	Unable to Rate	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree	List of the Parent-classes
Concepts **Tangible Capital Assets**	0	1	2	3	4	5	Parent classes------------to ------------Children classes
Infrastructure Sector Asset							
Transportation Sector Asset							
Masonary_Guard_Rail							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Transportation_Sector_Asset→Guard_Rail_Transportation_Asset→**Masonary_Guard_Rail**
Single_Tube_Tunnel							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Transportation_Sector_Asset→Tunnel_Transportation_Asset→**Single_Tube_Tunnel**
Suspension_Bridge							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Transportation_Sector_Asset→Bridge_Transportation_Asset→Form_Based_Bridge→**Suspension_Bridge**
Concrete_Bridge							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Transportation_Sector_Asset→Bridge_Transportation_Asset→Material_Based_Bridge→**Concrete_Bridge**
Transfer_Station							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Transportation_Sector_Asset→Building_Transportation_Asset→**Transfer_Station**
Traffic_Camera							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Transportation_Sector_Asset→Machinery_&_Equipment_Transportation_Asset→Monitoring_Equipment→**Traffic_Camera**

Table 5-1 Knowledge Representation (Ontology) Correctness							
	Agreement Level						
	Unable to Rate	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree	List of the Parent-classes
Concepts Tangible Capital Assets	0	1	2	3	4	5	Parent classes------------to ------------Children classes
Infrastructure Sector Asset							
Water Sector Asset							
Mainline_Water							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Water_Sector_Asset→Water_Line→Hierarchical_Water_Line_**Mainline**
Cement_Water_Line							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Water_Sector_Asset→Water_Line→Material_Water_Line→**Cement_Water_Line**
Tank							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Water_Sector_Asset→**Tank_Water**
Filteration_Facility_Water							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Water_Sector_Asset→Building_Water→**Filteration_Facility_Water**

Table 5-1 Knowledge Representation (Ontology) Correctness							
Concepts **Tangible Capital Assets**	**Agreement Level**						
	Unable to Rate	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree	List of the Parent-classes
	0	1	2	3	4	5	Parent classes------------to ------------Children classes
Infrastructure Sector Asset							
Wastewater Sector Asset							
Mainline_Sanitary_Wastewater							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Wastewater_Sector_Asset→Sanitary_Wastewater_Asset→Sanitary_Wastewater_Line→Hierarchical_Sanitary_Wastewater_Line→**Mainline_Sanitary_Wastewater**
Treatment_Facility							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Wastewater_Sector_Asset→Sanitary_Wastewater_Asset→Building_Sanitary_Wastewater→**Treatment_Facility**
Serviceline_Storm_Wastewater							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Wastewater_Sector_Asset→Storm_Wastewater_Asset→Storm_Wastewater_Line→Hierarchical_Storm_Wastewater_Line→**Serviceline_Storm_Wastewater**
Slab_Culvert							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Wastewater_Sector_Asset→Storm_Wastewater_Asset→Storm_Culvert_Storm_Wastewater_Asset→Form_Culvert_Storm_Wastewater_Asset→**Slab_Culvert**
Pond							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Wastewater_Sector_Asset→Storm_Wastewater_Asset→ **Pond**
Solidwaste Sector Asset							
Landfill							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Solidwaste_Sector_Asset→Land_Solidwaste_Asset→ **Landfill**
Sorting_Facility							Tangible_Capital_Asset→Sector_Based_Asset→Infrastructure_Sector_Asset→Solidwaste_Sector_Asset→Building_Solidwaste_Asset→**Sorting_Facility**

Table 5-1 Knowledge Representation (Ontology) Correctness							
	Agreement Level						
	Unable to Rate	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree	List of the Parent-classes
Concepts **Tangible Capital Assets**	0	1	2	3	4	5	Parent classes------------to ------------Children classes
Facility Sector Asset							
Recreational and Cultural Facility							
Museum_Facility							Tangible_Capital_Asset→Sector_Based_Asset→Facility_Sector_ Asset→ Recreational_&_Cultural_Facility→**Museum**
Library_Facility							Tangible_Capital_Asset→Sector_Based_Asset→Facility_Sector_ Asset→ Recreational_&_Cultural_Facility→**Library**
Senior_Center_Facility							Tangible_Capital_Asset→Sector_Based_Asset→Facility_Sector_ Asset→ Recreational_&_Cultural_Facility→**Senior_Cente**r
Protective Services Facility							
Building_Police_Protection (Police_Station)							Tangible_Capital_Asset→Sector_Based_Asset→Facility_Sector_ Asset→Protective_Services_Facility→Police_Protection_Facility→ **Building_Police_Protection**
Vehicle_Police_Protection (Police_Car)							Tangible_Capital_Asset→Sector_Based_Asset→Facility_Sector_ Asset→Protective_Services_Facility→Police_Protection_Facility→ **Vehicle_Police_Protection**
Equipment_Police_Protection							Tangible_Capital_Asset→Sector_Based_Asset→Facility_Sector_ Asset→Protective_Services_Facility→Police_Protection_Facility→ **Equipment_Police_Protection**
Please list coments, and specific issues, concerns, or errors that you have noticed:							

Section 6: Knowledge Representation (***Ontology***) Overall Assessment

6.1 Please record your overall assessment Table 6-1. Please select one of the choices shown in Table 6-1.

Table 6-1 Knowledge Representation (Ontology) Validation Overall Assessment

	Agreement Level						
	Unable to Rate	Strongly Disagree	Disagree	Undecided - Neither Agree Nor Disagree	Agree	Strongly Agree	
Overall Assessment	0	1	2	3	4	5	
Is the ontology provide a clear, correct, and complete representation of the transaction knowledge in the area of infrastructure management?							
Please list coments, and specific concerns, issues, or errors that you have noticed:							

Expert Review Survey Towards Tangible Capital Asset Ontology Validation

Glossary of Items

1. **Tangible Capital Asset**

Tangible capital assets are non-financial assets having physical substance that are acquired, constructed, or developed and: are held for use in the production or supply of goods and services; have useful lives extending beyond an accounting period; are intended to be used on a continuing basis, and are not intended for sale in the ordinary course of operations.

2. Data Modeling

Data modeling is the process of identifying entities, the relationship between those entities and their attributes. Data modeling is a method used to define and analyze data requirements needed to support the business processes of an organization.

3. Ontology Validation

Ontology validation refers to judging the content of the ontology from a real world perspective, to ensure that the ontological model accurately captures real world model of the domain of interest.

4. Ontology

Explicit and formal specification of a conceptualization.

Appendix I Transaction Formalism Protocol Tools/Techniques

I.1 Transaction Formalism Protocol Tools and Techniques

A set of Tools and techniques were identified for each step of the proposed TFP. According to DTI (2012), definition of various Tools and techniques are as follows.

i. *DRIVE*—is a problem solving technique with acronym stands for **D**efine, **R**eview, **I**dentify, **V**erify, and **E**xecute. The scope of the problem is defined (**D**efine); the background context is reviewed to know about the current situation of the problem (**R**eview); possible solutions to the problems are identified (**I**dentify); check that the proposed solution will result in achieving the desired benefits (**V**erify); and plan to implement the proposed solution (**E**xecute).

ii. *Mapping or process mapping*—allows users to create dynamic models of activities that are taking place in a process in order to understand the process clearly and identify opportunities for improvement. A map of a process is created at the macro (high-level process) and micro level (low-level process), and identifies inputs, controls, resources, and outputs for the top processes and sub-processes.

iii. *Flow chart or process flow charting*—allows users to record the flow of activities in a process using certain standard symbols in order to understand and analyze the process.

iv. *Force field analysis*—allows users to identify the positive and negative forces that help or resist the As-is or To-be process and transactions in order to assess problems associated with the As-is/To-be processes/transactions and evaluate improved process or transaction viability.

v. *Cause and effect diagram*—also known as *Fishbone or Ishikawa Diagram* is a problem solving technique that allows users to assess and analyze problems and its' causes. The *effect* refers to the problem represented through a central horizontal arrow and *causes* are represented through slanted converging arrows from the top and bottom of the horizontal line. The cause and effect analysis diagram is analogous to the bone structure of a fish.

vi. *Cause and effect diagram with the addition of cards (CEDAC)*—allows users to identify problems and its causes using two different colored cards for recording facts and ideas. The facts of a cause are recorded on the left of the cause spine and ideas (possible solutions) are recorded on the right of the cause spine.

vii. *Brainstorming*—allows users to generate a large number of ideas quickly. It is used to identify problems and improvement areas, proposing a viable solution to the problem and developing an action plan.

viii. *Pareto analysis*—assists users to identify the problems or causes that are the most important and have the greatest impact from the list generated at the outcome of the brainstorming. A Pareto chart is a bar chart representing problems or causes versus frequency of occurrence of the problems or causes in descending order. The causes and problems with the most frequency come first and with the lower frequency go towards the end of the chart. It is also called as 80/20 rule, which means 80% of the effects (problems) are attributed to 20% of the causes.

ix. *Check sheet/prescribed form*—assists users to collect data in the most efficient and organized manner to ensure that every user collect the right information in a consistent way.

x. *Benchmarking*—is a protocol that allows users to compare performance of organizations, processes, systems, etc. against a set-forth standard or criteria.

xi. *Survey*—allows users to ask questions from the respondents using electronic (e.g. telephone, web-based, etc.) or non-electronic (e.g. in-person interview, postal, etc.) modes of communication.

According to (Flyvbjerg, 2011), definition of case study and workshop is as follows.

i. *Case study*—is an intensive analysis of an individual unit (e.g. person, group, or event) stressing developmental factors in relation to contexts .

ii. *Workshop*—is a technique that allows a group of people to share their knowledge and experience through interactive discussion or practical work towards solving a problem.

iii. *SWOT*—according to Fine (2009), SWOT is a technique to identify and assess organizational strengths, weaknesses (limitations), opportunities, and threats to develop a set of achievable organizational goals.

iv. *Stakeholder analysis*—according to Gord (2010), stakeholder analysis is a technique used to identify various stakeholders, their level of interest, involvement, and requirements, and how different interests and involvements influence an organization, project, or process.

According to OMG (2012), definitions of different UML diagrams, data flow diagram, and workflow diagram are as follows.

i. *ebXML sequence diagram, UML sequence diagram, and UML conversation diagram*—represents the interactions or flow of messages that are exchanged between various partners in a given collaboration.

ii. *UML data flow diagram*—represents the flow of data or information in a process based on the inputs and outputs.

iii. *Workflow diagram*—represents the flow of a set of sequenced activities in a given process.

According to W3C (2008), definitions of different languages are as follows.

i. *Ontology web language (OWL) and resource description framework (RDF)*—are knowledge representation languages that are used to develop ontologies. The OWL is richer than RDF in terms of syntax and semantics to represent knowledge in a domain of interest.

ii. *Extensible markup language (XML)*—is a meta language designed to store, transport, and structure data in a format that is both human and computer readable.

iii. *Microsoft infoPath designer*—according to Paoli (2003), it is a Microsoft Office based application that is used to design, distribute, fill, and submit electronic forms.

Appendix J Transaction Formalism Protocol Naming Rules

J.1 Naming Rules for Transaction Formalism Protocol

To name various elements of the transaction using the proposed TFP, a set of naming rules is developed in the line with the Information Delivery Manual (IDM) naming rules. According to IDM (2007), names are to be written in lowercase with each word separated by an underscore. In this research work, naming rules are developed for the following three elements of a transaction.

J.1.1 Naming Rules for Transaction Maps (TMs)

The specific names of the As-is and To-be TMs consist of two parts. The *first part* is the prefix “tm” representing a transaction map and the *second part* is the subject of the transaction and is expressed as a noun or noun phrase. The second part of the name may have other parameters to specify a name unambiguously. These parameters include; sector to which a transaction belongs, the mode of the project delivery, type of collaboration (bilateral or multi-lateral transaction), type of transaction patterns (one/two action with/without acknowledgment), type of business transaction (commercial, financial, or information transaction), interface transaction (internal or external transaction), etc. that is shown within the ( ), { }, or [ ]. For example, the name of the Tangible Capital Asset (TCA) reporting between the municipal and provincial government can be written as tm_tca, tm_tca_(w), tm_tca_(ww), tm_tca_(tpt), tm_tca_(bldg), tm_tca_{govt_to_govt}, and tm_tca_(internal/external), where the words “w, ww, tpt, bld” represents the water, wastewater, transportation, building sectors respectively. The prefix “tm” can have a subscript as_is or to_be to differentiate between the As-is and To-be transaction maps, e.g. tm_{as_is}_tca or tm_{to_be}_tca.

Moreover, each transaction or transaction map consists of a single or set of atomic transactions (sole exchange of information between two parties). These atomic transactions have names that consist of five parts. The *first part* is the prefix “tm” representing the name of the transaction map to which an atomic transaction belongs. The *second part* is the subject of the transaction or transaction map. The *third part* relates to the sequence number of atomic transactions denoted by “$atom_{1,\,2,3\ldots..}$”, wherein “atom” represents an atomic transaction and “1,2,3, ….”, shows the sequence in which atomic transactions are taking place between two or more parties. The *fourth part* represents the function of an atomic transaction (e.g. action, signal/acknowledgment). The *fifth part* represents the subject of the atomic transaction. All parts are expressed as nouns or noun phrases except part 4 that is expressed as a verb.

For example, names of atomic transactions 1, 3, and 6 in TCA reporting transaction is $tm_{As\text{-}is}$ (prefix)_tca (subject of transaction map)_$atom_1$ (name and sequence of atomic transaction)_request (function)_tca info (subject of atomic transaction), $tm_{As\text{-}is}$_tca_$atom_3$_submit_tca info, and $tm_{As\text{-}is}$_tca_$atom_6$_send_tca info. Moreover, the subscript As-is is to be replaced with To-be for names of atomic transactions in To-be transaction maps, e.g. $tm_{To\text{-}be}$_tca_$atom_1$_request_tca.

J.1.2 Naming Rules for Information

A transaction is composed of a set of atomic transactions wherein some information is exchanged between the parties. Therefore, information is to be defined for each atomic transaction. Information element has a name consisting of three parts. The *first part* is the prefix "info" representing information that includes both the header and payload information. The *second part* is the subject of the transaction, whereas the *third part* is the sequence number of an atomic transaction through which information is exchanged between the parties. Both the parts two and three are expressed as nouns or noun phrases and should be exactly the same as shown in part two and three of the transaction maps. For example, the name of the information element for atomic transaction 1 in Tangible Capital Asset reporting is info_tca_$atom_1$, or $info_{as_is}$_tca_$atom_1$ or $info_{to_be}$_tca_$atom_1$. For subsequent atomic transactions, $atom_1$ is to be replaced with $atom_2$, $atom_3$, and so on.

J.1.3 Naming Rules for Message Templates

The message templates represent the header and payload information that needs to be exchanged between the parties to accomplish a transaction successfully. Each message template is exchanged between the parties in each atomic transaction. Each message template has a name consisting of three parts. The *first part* is the prefix "mt" representing a message template, whereas the *second part* and *third part* of the name of a message template follows exactly the same terms and definitions developed for the information element. The only difference between the names of information and message template elements is the prefix. For example, the name of the message template element for atomic transaction 1 in Tangible Capital Asset reporting is mt_tca_$atom_1$, or mt_{as_is}_tca_$atom_1$ or mt_{to_be}_tca_$atom_1$. For subsequent atomic transactions, $atom_1$ is to be replaced with $atom_2$, $atom_3$, and so on.

The *third part* of the name may have other parameters to specify a name unambiguously. These parameters pertain to various functions that a message template performs in a given transaction, e.g. action message (request, perform, design, supply, etc.) or signal message (receipt/accept/admit/confirm/inform message). These parameters can be shown within ( ), { }, or [ ]. For example, mt_tca_$atom_1$_(action), or mt_{as_is}_tca_$atom_1$_(action) or mt_{to_be}_tca_$atom_1$_(action) and mt_tca_$atom_1$_(signal), or mt_{as_is}_tca_$atom_1$_(signal) or mt_{to_be}_tca_$atom_1$_(signal).

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Appendix K Transaction Formalism Protocol Tool Application

K.1 Application of Transaction Formalism Protocol Tool—(Filled Forms)

The TFP Tool was applied in the domain of infrastructure management through defining the Asset Inventory and Condition Assessment Reporting/Tangible Capital Asset (AI&CAR/TCA) Reporting. In this process, municipal governments report their TCA information to the provincial government for financial planning and budget allocations. The proposed TFP Tool was used to formalize the AI&CAR/TCA Reporting for further implementation into a prototype Asset Information Integrator System (AIIS) developed as part of this research work. The AIIS collects, integrates, and analyzes the TCA information received from different municipalities. While formalizing the AI&CAR/TCA Reporting, all the forms of the proposed TFP Tool were filled using the case study and expert interview approaches as described below.

K.1.1 Step 1—Asses Needs

The asses needs form is shown in Figure K-1. The general administrative information captures the name and E-mail address of the person who has filled the form. Also, it shows the date at which the form was filled.

Assess Needs - Step 1									
General Administrative Information									
Name	XYZ								
E-mail Address									
Date Conducted	30/05/12 (dd/mm/yy)								
Technical Information									
Description of Transaction Selection									
Experts in the domain of infrastructure management identified a list of transactions that have the greatest potential for IT improvement. All the identified transactions obtained same scores; however, it is decided to formalize tangible capital asset reporting transaction first, due to urgent compliance with the Public Sector Accounting Board reporting requirement. Moreover, other transactions on the list will be formalized later.									
Assessment Criteria - (tick all that applies)									
Single or List of Transaction	**Manual/ Paper-based**	**Critical**	**Costly**	**Frequent**	**Liklihood of Mgt.**	**Complex**	**Contractual Req.**	**Regulatory Req.**	**Total Score**
i. Tangible capital asset reporting (PSAB-3150)	√		√			√		√	4
ii. Asset inventory & condition assesssment reporting	√		√			√		√	4
iii. Pavement condition assessment reporting	√		√			√		√	4
iv. Request for proposal	√	√			√		√		4
v. Submission of project as-built information				√	√		√	√	4
vi. Request for services		√		√	√		√		4

Figure K-1 Assess needs—filled form

In the technical information, description of the transaction selection summarizes the process of identification and selection of the TCA reporting in the domain of infrastructure management. The assessment criteria section shows the evaluation of transactions in the domain of infrastructure management using the criteria shown in Figure K-1.

K.1.2 Step 2—Define As-is Transaction Map

In this step, the As-is TM was defined for the AI&CAR/TCA Reporting as shown in Figure K-2. The general administrative information shows the name of the As-is TM, identifier, and the change log representing the date, status of the As-is TM, and the E-mail address of the person who has filled the form.

Step - 2 Define As-is Transaction Map						
General Administrative Information						
Name	$tm_{as\text{-}is}$_tca_reporting					
Identifier						
Change Log	**Date (dd/mm/yy)**	**Status**		**E-mail**		
	30/04/2013	Created				
Technical Informtion						
As-is Transaction Map Definition, Purpose, and Scope						
Definition - This transaction relates to the exchange of asset information between different municipalities and the provincial government. **Purpose** - The purpose of this transaction is to enable different municipalities to report asset inventory and condition assessment information seamlessly to the provincial government for financial planning and fund allocation. **Scope** - This transaction is taking place between the municipal and provincial governement; however, sometime asset information for ongoing projects resides with consultants and/or contractors/developer that require the exchange of asset information to take place between multi-parties. The core asset information that is to be exchnaged between the parties relates to the water, waste water, and transportation sectors in addition to other asset information.						
As-is Transaction Map Specification						
Name of Atomic Transaction		**From**		**To**		**Mode of Communication**
Generic Name	**Specific Name**	**Designation**	**Organization**	**Designation**	**Organization**	
request tca information	$tm_{as\text{-}is}$_tca_atom$_1$_request_tca info.	Mgr. Finance	Municipality	Mgr. Engg.	Municipality	E-mail, Server based, Meeting, Tel., CD
request tca information	$tm_{as\text{-}is}$_tca_atom2_request_tca info.	Mgr. Engg.	Municipality	Co-ord. Engg.	Consultant	E-mail, Server based, Meeting, Tel., CD, Post Mail
submit tca information	$tm_{as\text{-}is}$_tca_atom3_submit_tca info.	Co-ord. Engg.	Consultant	Mgr. Engg.	Municipality	E-mail, Server based, Meeting, Tel., CD, Post Mail
submit tca information	$tm_{as\text{-}is}$_tca_atom4_submit_tca info.	Mgr. Engg.	Municipality	Account. Eng.	Municipality	E-mail, Server based, Meeting, Tel., CD
submit tca information	$tm_{as\text{-}is}$_tca_atom5_submit_tca info.	Mgr. Engg.	Municipality	Mgr. Finance	Municipality	E-mail, Server based, Meeting, Tel., CD
send tca information	$tm_{as\text{-}is}$_tca_atom6_send_tca info.	Mgr. Finance	Municipality	Admin. Council	Municipality	E-mail, Server based, Meeting, Tel., CD
send tca information	$tm_{as\text{-}is}$_tca_atom7_send_tca info.	Mgr. Finance	Municipality	Asset Co-ord.	Prov. Govt.	E-mail, Server based, Meeting, Tel., CD, Post Mail
Graphical Representation						
Two formal sequence diagrams are created in UML for the As-is transaction map specification mentioned above using the generic and specifc names from general user and developer perspective.						
As-is Transaction Performance Criteria **Note: Rating criteria is "H" for High, "M" for Medium, "L" for Low, and "N" for None or Not at all Easy or Not Applicable**						
Time (person-hrs)	**Rate**	**Cost ($)**	**Rate**	**Quality**	**Rate**	
Transaction formulation time	H	**Transaction formulation cost**	H	**Level of message interpretability**	L	
Transaction transmission time	H	**Transaction transmission cost**	H	**Level of message structuring**	L	
				Ease of handling, tracking & retrieval	L	

Figure K-2 Define As-is transaction map for the AI&CAR/TCA reporting—filled form

The technical information captures As-is TM definition, purpose and scope, As-is TM specification, graphical representation, and As-is transaction performance criteria.

The technical information related to the definition, purpose, and scope of the As-is AI&CAR/TCA Reporting was presented first. Then, As-is TM specification was completed in terms of identifying the number and sequence of atomic transactions. For each atomic transaction, the name, sender and receiver roles (along with their organizational affiliation) and the current mode of communication were defined.

The graphical representation represents the As-is TM of the AI&CAR/TCA Reporting. The unified modeling language (UML) sequence diagrams of the As-is TM in terms of the generic and specific names of the atomic transactions are shown in Figure K-3 and Figure K-4 respectively. Moreover, the As-is TM performance for AI&CAR/TCA Reporting was defined against a set of performance criteria: time, cost, and quality.

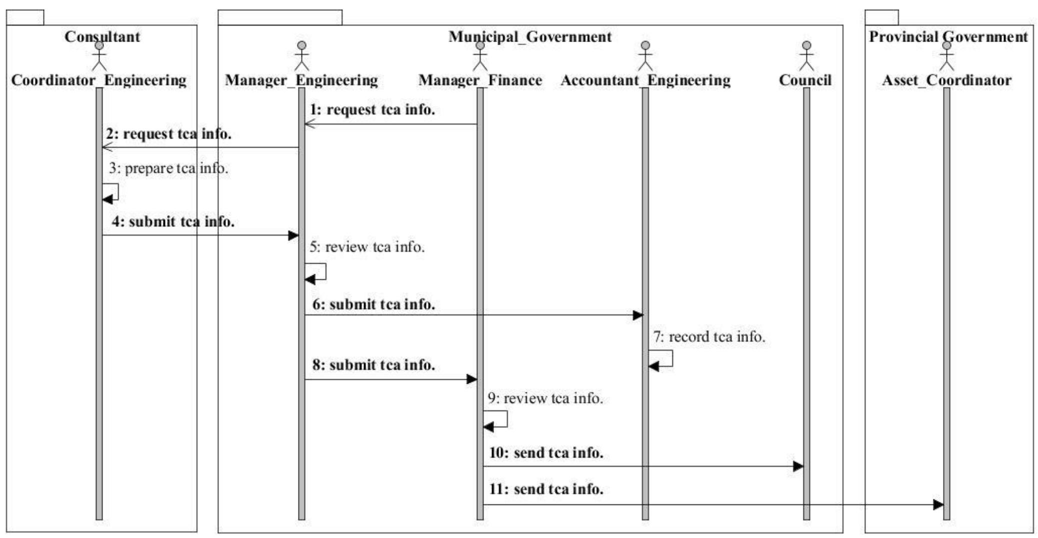


Figure K-3 UML sequence diagram of the As-is transaction map using generic names of atomic transactions

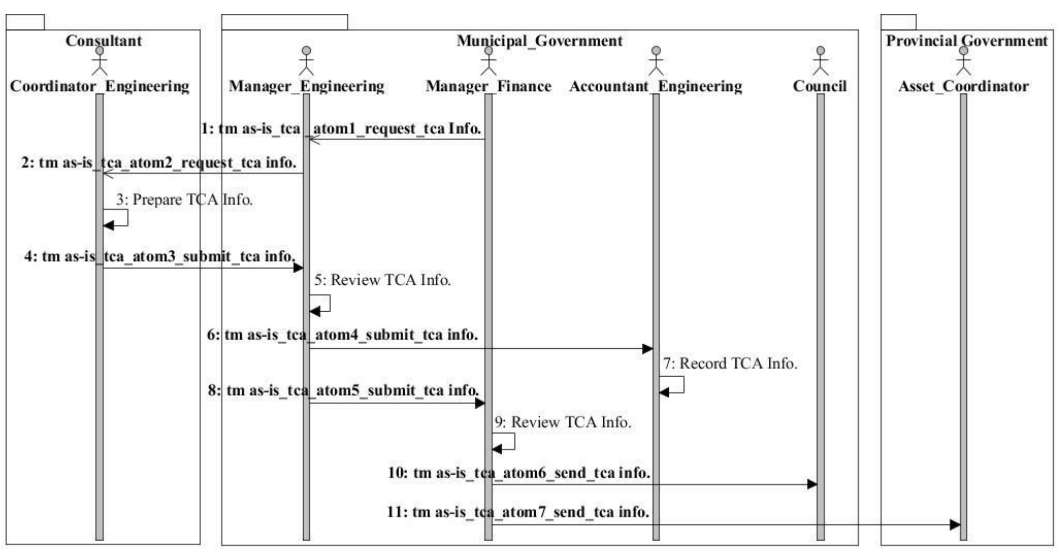


Figure K-4 UML sequence diagram of As-is transaction map using specific names of atomic transactions

K.1.3 Step 3—Develop To-be Transaction Map

The To-be TM of the AI&CAR/TCA/TCA reporting process was developed in this step as shown in Figure K-5.

Step - 3 Develop To-be Transaction Map			
General Administrative Information			
Name	tm$_{to\text{-}be}$_tca_reporting		
Identifier			
Change Log	**Date (dd/mm/yy)**	**Status**	**E-mail**
	5/30/2012	Created	
Technical Informtion			

Summary of Proposed Improvements

The following is a brief summary of the improvements proposed to the As-is TM.
i. **Process improvement -** the As-is communication process is to be modified for some transactions to tranform it from one/two action with no acknowledgement to one/two action with acknowledgement transactions.
ii. **Information improvement -** it is proposed that the TCA information is to be defined and well structured in a message form as part of the atomic transaction so that it can be interpretable by the receiving system.
iii. **Mode improvements -** current modes of communication adopted for TCA information is to be transformed with an efficient and effective mode of communication - message template based exchange of information through a web-based system.

To-be Transaction Map Specification

Name of Atomic Transaction		From		To		Proposed Improvements			
Generic Name	**Specific Name**	**Designation**	**Organization**	**Designation**	**Organization**	**Process Improv.**	**Infor. Improv.**	**Mode Improv.**	**Description of Proposed Improv.**
request tca information	tm$_{to\text{-}be}$_tca_atom$_1$_ request_tca info.	Mgr. Finance	Municipality	Mgr. Engg.	Municipality		√	√	Information is to be defined & communication mode is to be changed from E-mail/Server/Tel/ CD/Post-mail to template based exchange.
request tca information	tm$_{to\text{-}be}$_tca_atom2_ request_tca info.	Mgr. Engg.	Municipality	Co-ord. Engg.	Consultant		√	√	Ditto
receipt acknowledgement tca information	tm$_{to\text{-}be}$_tca_atom3_ receipt_ ackow._tca info.	Co-ord. Engg.	Consultant	Mgr. Engg.	Municipality	√	√	√	Ditto In addition to above, process is to be improved.
submit tca information	tm$_{to\text{-}be}$_tca_atom4_ submit_tca info.	Co-ord. Engg.	Consultant	Mgr. Engg.	Municipality		√	√	Ditto
accept acknowledgement tca information	tm$_{to\text{-}be}$_tca_atom5_ accept_ ackow._tca info.	Mgr. Engg.	Municipality	Co-ord. Engg.	Consultant	√	√	√	Ditto In addition to above, process is to be improved.
submit tca information	tm$_{to\text{-}be}$_tca_atom6_ submit_tca info.	Mgr. Engg.	Municipality	Account. Eng.	Municipality		√	√	Ditto
submit tca information	tm$_{to\text{-}be}$_tca_atom7_ submit_tca info.	Mgr. Engg.	Municipality	Mgr. Finance	Municipality		√	√	Ditto
send tca information	tm$_{to\text{-}be}$_tca_atom8_ send_tca info.	Mgr. Finance	Municipality	Admin. Council	Municipality		√	√	Ditto
send tca information	tm$_{to\text{-}be}$_tca_atom9_ send_tca info.	Mgr. Finance	Municipality	Asset Co-ord.	Prov. Govt.		√	√	Ditto
accept acknowledgement tca information	tm$_{to\text{-}be}$_tca_atom10_ receipt_ acknow_tca info.	Asset Co-ord.	Prov. Govt.	Mgr. Finance	Municipality	√	√	√	Ditto In addition to above, process is to be improved.

Graphical Representation

Two formal sequence diagrams are created in UML for the To-be Transaction Map specification mentioned above using the generic and specifc names from general user and developer perspective.

To-be Transaction Performance Criteria
Note: Rating Criteria is "H" for High, "M" for Medium, "L" for Low, and "N" for None or Not at all Easy or Not Applicable

Time (person-hrs)	Rate	Cost ($)	Rate	Quality	Rate
Transaction formulation time	L	**Transaction formulation cost**	L	**Level of message interpretability**	H
Transaction transmission time	L	**Transaction transmission cost**	L	**Level of message structuring**	H
				Ease of handling, tracking & retrieval	H

Figure K-5 Develop To-be transaction map of AI&CAR/TCA reporting—filled form

The general administrative information represents the name of the To-be TM, identifier; if any, and the change log showing the date, status and E-mail address of the person who has developed the To-be TM.

The technical information captures summary of the proposed improvements, To-be TM specification, graphical representation, and To-be transaction performance criteria as explained below.

The summary of proposed improvements briefly describes the proposed improvements in the AI&CAR/TCA Reporting process in terms of the process improvement, information improvement, and mode improvement.

The To-be TM specification represents the development of the To-be TM in terms of identifying and defining the number and sequence of atomic transactions. All the atomic transactions that formed the To-be TM of the AI&CAR/TCA Reporting process were listed and named accordingly. The actor roles along with their organization affiliations were defined for each atomic transaction. In addition, improvements; if any, were proposed against each atomic transaction.

The graphical representation captured an informal graphical representation of the To-be TM of the AI&CAR/TCA Reporting process while defining it with industry experts. Later, it was formally defined in the UML and a sequence diagram of the To-be TM of the AI&CAR/TCA Reporting is represented in Figure K-6 and Figure K-7, using generic and specific names of atomic transactions respectively. The atomic transactions shown with bold lines indicate newly added atomic transactions. The To-be TM for the AI&CAR/TCA Reporting was developed based on the assumption that the TCA data was to come from the consultants. This process could could be different, if the TCA data were to come from within the department or a private developer. Accordingly, this process could be adjusted.

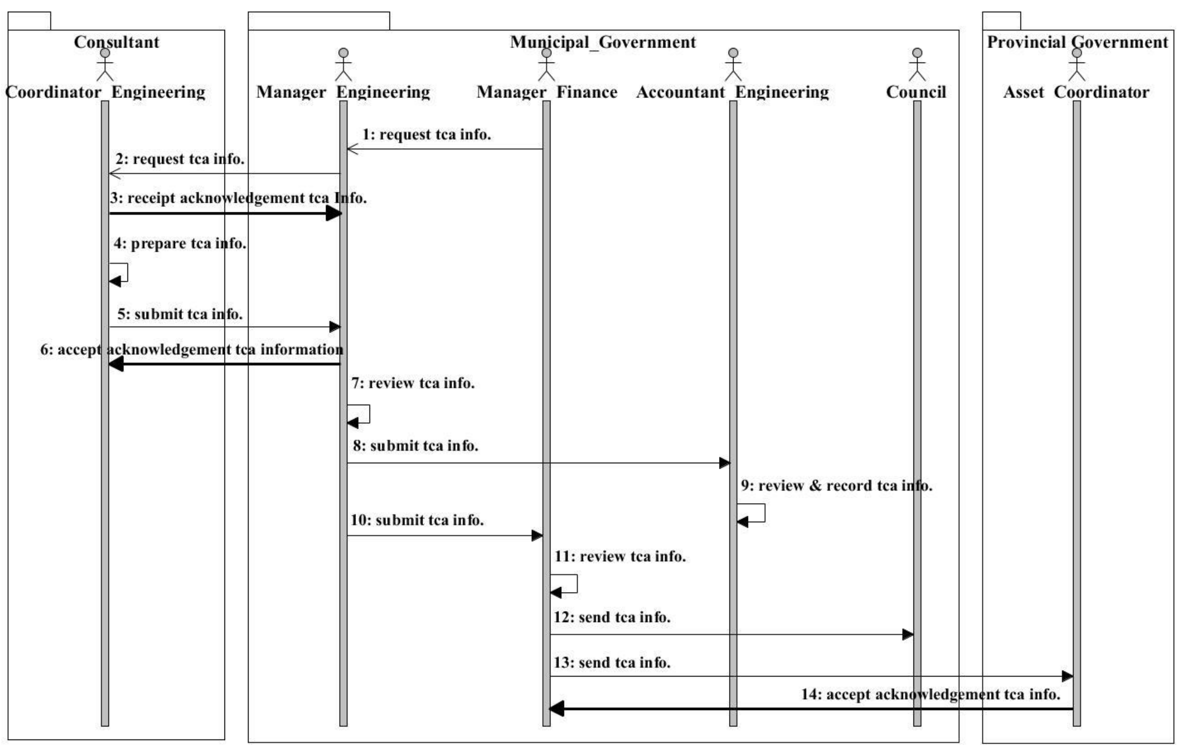


Figure K-6 UML sequence diagram of To-be transaction map using generic names of atomic transactions

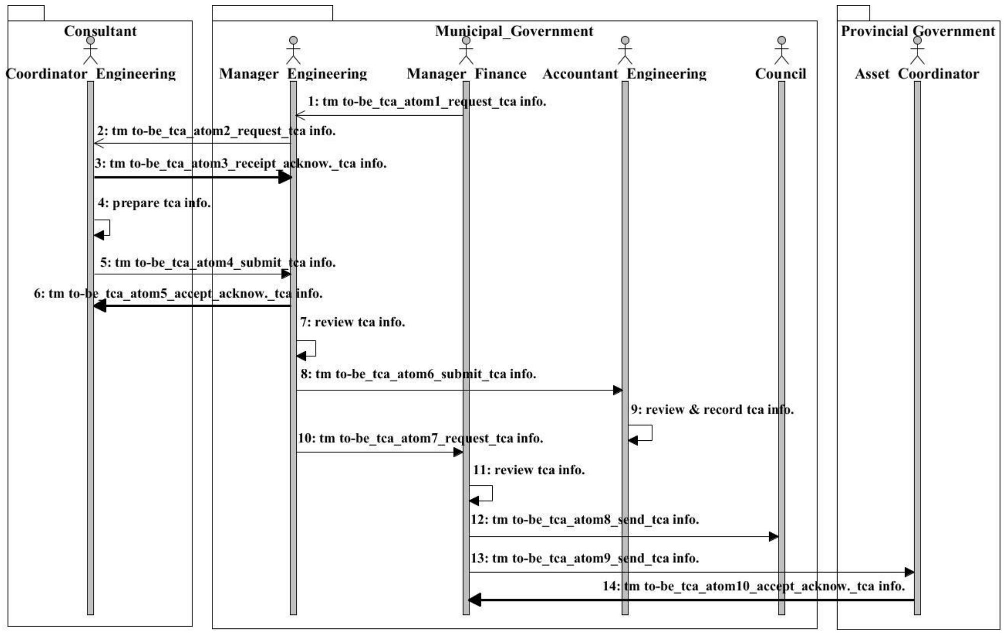


Figure K-7 UML sequence diagram of To-be transaction map using specific names of atomic transactions

K.1.4 Step 4—Collect Information

In this step, information was defined for each atomic transaction of the To-be TM of the AI&CAR/TCA Reporting. This information represents the exchange requirements in each atomic transaction that the parties involved in the AI&CAR/TCA Reporting process require to exchange through MTs to accomplish a transaction successfully. A MT represents this information as the header and payload information; therefore, for each MT of the AI&CAR/TCA Reporting process, header and payload information were specified separately as shown in Figure K-8 and Figure K-9 respectively. The header information is the meta information about a transaction and message; whereas the payload information is the actual information content that parties need to exchange to accomplish a transaction successfully.

K.1.4.1 Specification of Header Information

The header information was specified for each atomic transaction of the To-be TM of AI&CAR/TCA Reporting process in three different categories: preamble, delivery, and service header information. For each of the three header information, a set of attributes was already defined as shown in Figure K-8 that eases identification and specification of the header information for a given MT. The transaction development personnel have the flexibility to define other attributes for these three categories of header information, if they think it is important to be represented in a MT in a specific context. A brief description of the header information specification is as follows.

First, all atomic transactions, defined in the To-be TM of AI&CAR/TCA Reporting process, were listed in column 1 of Figure K-8. Second, the header information attributes were checked/ticked from the set of identified attributes for each MT of an atomic transaction. Each of the checked attributes was ranked as required, optional, or not applicable. A required information (REQ) attribute is the one that must be provided in a MT whereas the optional information (OPT) attribute may be provided in a MT and is left at the discretion of the user based on their specific requirements. The not applicable, (N/A) attribute is the information that is not required to be exchanged in a MT. Information ranking is important because different users have different requirements in different transactions. Moreover, location specific attributes specification was not done in the AI&CAR/TCA Reporting as it was not required in the given context.

Step - 4 Collect Information																		
Specification of Header Information																		
Name of Atomic Transaction, (To-be Transaction Map)	**Rank Header Info.**	**Preamble Header Info.**	**Delivery Header Info.**										**Service Header Info.**					
		Reference Info.	**Actor Info.**	**Actor Role Info.**		**Temporal Info.**						**Security Info.**	**Transaction General Info.**				**Message General Info.**	
		Header Information Attributes - NOTE: Apply tick "√" all that applies																
		Data Model/ Ontology Version	**Name/ Address/ Fax/Tel**	**Role TrackingID**	**Sender/ Receiver Role**	**Transaction Duration**	**Transaction Start/End Date**	**Message Duration**	**Receipt/Accept Signal Duration**	**Respond to Action Duration**	**Message Sent/ Receivd Data**	**High/Medium/ Low Security**	**Transaction Name**	**Transaction Purpose**	**Transaction Definition**	**Transaction Affiliation**	**Message Purpose**	**Message Definition**
tm$_{to-be}$_tca_atom$_{1}$_request_ tca info.	**REQ**		√		√						√		√					
	OPT	√		√		√	√	√	√	√		√		√	√	√	√	√
	N/A																	
tm$_{to-be}$_tca_atom$_{2}$_request_ tca info.	**REQ**		√		√						√		√					
	OPT			√		√	√	√	√	√		√		√	√	√	√	√
	N/A	√																
tm$_{to-be}$_tca_atom$_{3}$_receipt_ ackow._tca info.	**REQ**		√		√						√		√					
	OPT			√		√	√	√	√	√		√		√	√	√	√	√
	N/A	√																
tm$_{to-be}$_tca_atom$_{4}$_submit_ tca info.	**REQ**		√		√						√		√					
	OPT			√		√	√	√	√	√		√		√	√	√	√	√
	N/A	√																
tm$_{to-be}$_tca_atom$_{5}$_accept_ ackow._tca info.	**REQ**		√		√						√		√					
	OPT			√		√	√	√	√	√		√		√	√	√	√	√
	N/A	√																
tm$_{to-be}$_tca_atom$_{6}$_submit_ tca info.	**REQ**		√		√						√		√					
	OPT			√		√	√	√	√	√		√		√	√	√	√	√
	N/A	√																
tm$_{to-be}$_tca_atom$_{7}$_submit_ tca info.	**REQ**		√		√						√		√					
	OPT			√		√	√	√	√	√		√		√	√	√	√	√
	N/A	√																
tm$_{to-be}$_tca_atom$_{8}$_send_ tca info.	**REQ**		√		√						√		√					
	OPT			√		√	√	√	√	√		√		√	√	√	√	√
	N/A	√																
tm$_{to-be}$_tca_atom$_{9}$_send_ tca info.	**REQ**		√		√						√		√					
	OPT			√		√	√	√	√	√		√		√	√	√	√	√
	N/A	√																
tm$_{to-be}$_tca_atom$_{10}$_accept_ acknow_tca info.	**REQ**		√		√						√		√					
	OPT			√		√	√	√	√	√		√		√	√	√	√	√
	N/A	√																
Specification of Location Specific Header Information, if any.																		
Name of Atomic Transaction, (To-be Transaction Map)	**Rank Header Info.**	**Preamble Header Information**	**Delivery Header Information**										**Service Header Information**					
		Header Information Attributes - NOTE: Apply tick "√" all that applies																
	REQ																	
	OPT																	
	N/A																	

Figure K-8 Header information specification for the AI&CAR/TCA reporting—(filled form)

K.1.4.2 Specification of Payload Information

The payload information for the AI&CAR/TCA Reporting process was defined using the form shown in Figure K-9.

Step - 4 Collect Information

Specification of Payload Information

Name of Atomic Transaction, (To-be Transaction Map)	Payload Information	Rank Payload Information			Attribute(s) of Payload Information												
	Description	REQ	OPT	N/A	Project Name	Project Work Order #	Project Location	Land Dev. Project #	Quantity/Disposed Qty.	Cost Inc. Overheads	Acquisition Cost	Net Book Cost	Condition Index	Average Age	Remaining Life	Replacement Cost	
tm$_{to\text{-}be}$_tca_atom$_1$_request_tca info.	Message body info.	√															
	Project info.		√		√	√		√									
	Project location info.		√				√										
tm$_{to\text{-}be}$_tca_atom$_2$_request_tca info.	Message body info.	√															
	Project info.		√		√	√		√									
	Project location info.		√				√										
tm$_{to\text{-}be}$_tca_atom$_3$_receipt_ackow._tca info.	Message body info. showing	√															
	reciept acknowledgement																
tm$_{to\text{-}be}$_tca_atom$_4$_submit_tca info.	Project info.		√		√	√		√									
	Project location info.		√				√										
	Tangible capital asset info. (asset category level)	√							√	√							
tm$_{to\text{-}be}$_tca_atom$_5$_accept_ackow._tca info.	Message body info.	√															
	showing accept acknowledgement																
tm$_{to\text{-}be}$_tca_atom$_6$_submit_tca info.	Project info.		√		√	√		√									
	Project location info.		√				√										
	Tangible capital asset info.	√							√	√							
tm$_{to\text{-}be}$_tca_atom$_7$_submit_tca info.	Project info.		√		√	√		√									
	Project location info.		√				√										
	Tangible capital asset info.	√							√	√							
tm$_{to\text{-}be}$_tca_atom$_8$_send_tca info.	Tangible capital info. (municipality level)	√							√		√	√	√	√	√	√	√
	Tangible capital info. (category level)								√		√	√	√	√	√	√	√
tm$_{to\text{-}be}$_tca_atom$_9$_send_tca info.	Tangible capital info. (municipality level)	√							√		√	√	√	√	√	√	√
	Tangible capital info. (category level)								√		√	√	√	√	√	√	√
tm$_{to\text{-}be}$_tca_atom$_{10}$_accept_acknow_tca info.	Message body info. showing	√															
	receipt acknowledgement																

Specification of Location Specfic Payload Information, if any.

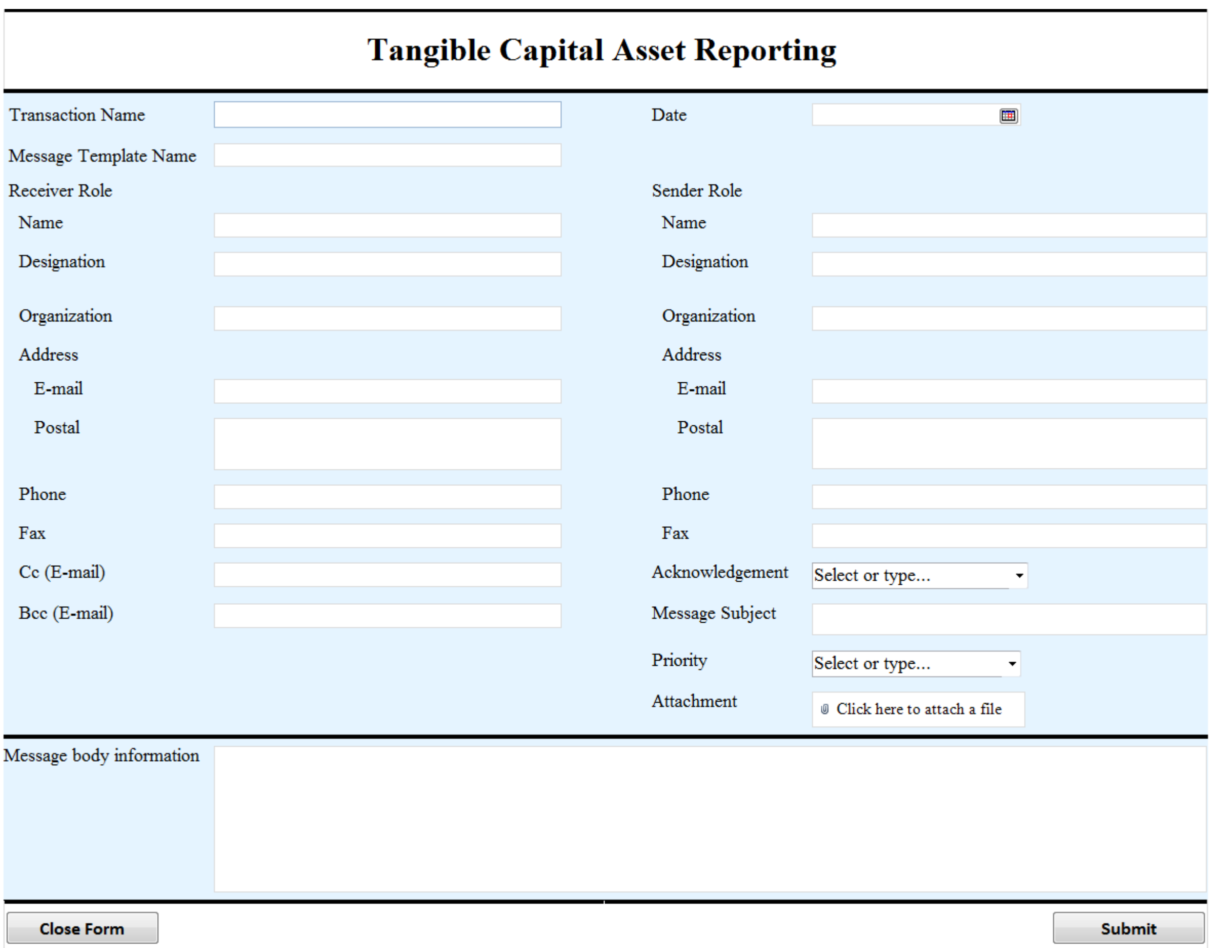
Name of Atomic Transaction, (To-be Transaction Map)	Payload Information	Rank Payload Information			Attribute(s) of Payload Information												
	Description	REQ	OPT	N/A													

Figure K-9 Payload information specification for the AI&CAR/TCA reporting—(filled form)

First, all atomic transactions defined for the To-be TM of the AI&CAR/TCA Reporting process were listed in the first column of Figure K-9, using specific names of atomic transactions. In the second column, payload information was identified and described briefly against each atomic transaction. In the third column, each of the identified payload information was ranked as required, optional, or not applicable. In the fourth column, a set of attributes was defined for each information identified in column 2 against each atomic transaction. All information attributes were checked/ticked that needs to be exchanged in a given atomic transaction. Moreover, location specific specification of payload information was not made as it was not required in the given context.

K.1.5 Step 5—Design Message Template

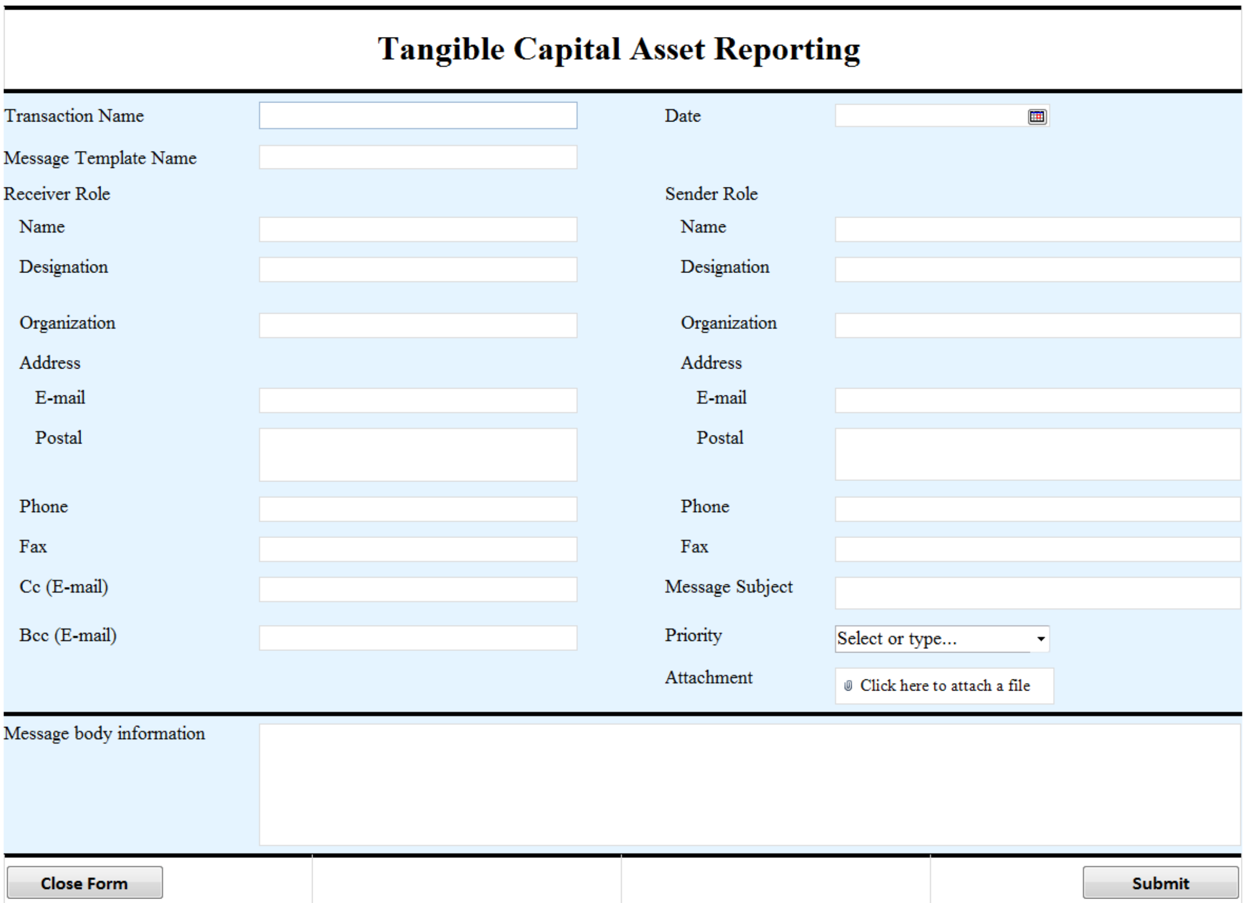
A MT was designed for each atomic transaction identified in the To-be TM of the AI&CAR/TCA Reporting process. Each MT represents the header and payload information collected for that specific atomic transaction. The MTs were designed using the Microsoft InfoPath application because of its' low cost, ease of use, and readily availability. There were ten atomic transactions as per the To-be TM of the AI&CAR/TCA Reporting process. In atomic transaction 1 and 2, parties request to report the TCA information. The MT represented in Figure K-10 was used while requesting other parties to report the TCA information.


Tangible Capital Asset Reporting

Transaction Name
Date
Message Template Name
Receiver Role
Name
Designation
Organization
Address
E-mail
Postal
Phone
Fax
Cc (E-mail)
Bcc (E-mail)
Sender Role
Name
Designation
Organization
Address
E-mail
Postal
Phone
Fax
Acknowledgement
Select or type...
Message Subject
Priority
Select or type...
Attachment
Click here to attach a file
Message body information
Close Form
Submit

Figure K-10 Message template defined for atomic transaction 1 and 2—request TCA information

In response to the atomic transaction 2, a receipt acknowledgement message shown in Figure K-11 was sent to the sender through atomic transaction 3. This was to confirm that a request for the TCA reporting was received. This MT was used in the accept acknowledgment and other receipt atomic transactions (e.g. 5 and 10) of the To-be TM of the AI&CAR/TCA Reporting process. In both the receipt and accept acknowledgment MTs, the message body information represents the information content that either confirms receipt of a request or confirms acceptance of the TCA information received. The message body information field was designed as an open-ended text and the users have the flexibility to write confirmation or acceptance of the TCA information in their own wordings.


Tangible Capital Asset Reporting

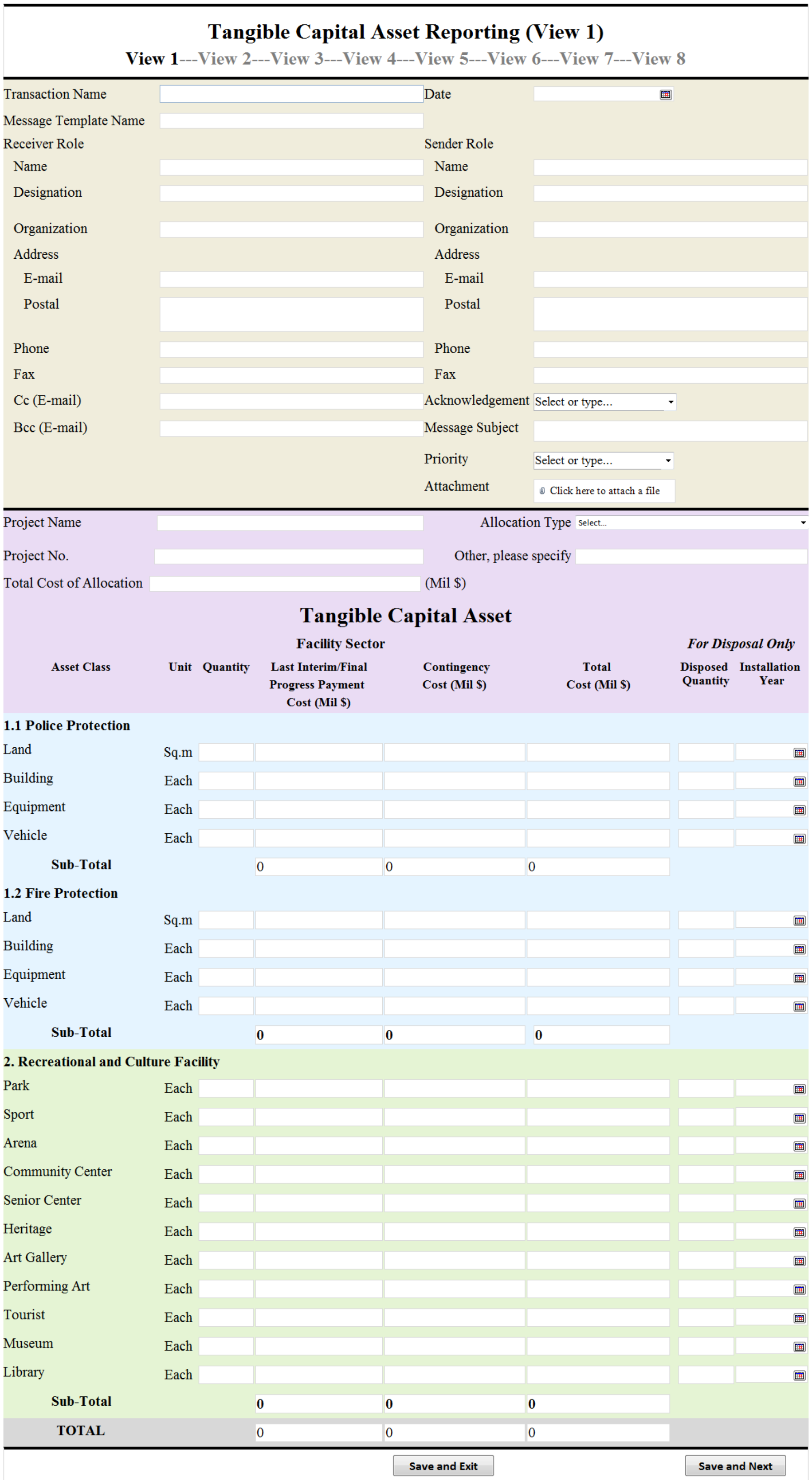
Transaction Name
Date
Message Template Name
Receiver Role
Name
Designation
Organization
Address
E-mail
Postal
Phone
Fax
Cc (E-mail)
Bcc (E-mail)
Sender Role
Name
Designation
Organization
Address
E-mail
Postal
Phone
Fax
Message Subject
Priority
Select or type...
Attachment
Click here to attach a file
Message body information
Close Form
Submit

Figure K-11 Message template used in atomic transaction 3 and 10—receipt acknowledgement

If the TCA information was prepared by the consultant of the respective project(s), it was then reported to the engineering section of the municipality through atomic transaction 4. The TCA information was reviewed at the engineering section to avoid any discrepancies and then the reviewed TCA information was reported to the accountant and manager finance of the account section via atomic transaction 6 and 7 respectively. In atomic transaction 4, 6, and 7, same MT was used to submit the TCA information. The MT designed for these atomic transactions represents the TCA information that is grouped according to five sectors: facility, transportation, water, wastewater, and solid waste management. This is a multi-view MT in which each view represents the TCA information related to a specific infrastructure sector or sub-sector.

The view 1 of this MT represents the TCA information in terms of different facilities (see Figure K-12). View 2 (see Figure K-13) shows road transportation assets and view 3 (see Figure K-14) shows bridge transportation assets. View 4 represents the water sector assets (see Figure K-15) while view 5 (see Figure K-16) and view 6 (see Figure K-17) shows the sanitary and storm wastewater assets respectively. View 7 shows the solid waste management assets (see Figure K-18). Finally, view 8 shows the sectoral cost summary (see Figure K-19).

This is a multi-view generic MT designed to suit reporting of the TCA information by all different types of municipalities: city, district, town, a village. A city municipality may own and operate many TCAs in comparison to a village municipality or district municipality; therefore, a generic MT was designed to fulfill requirements of all types of municipalities. The users should fill only those fields of the MT that are applicable to them and leave other fields blank that are not applicable.



Tangible Capital Asset Reporting (View 1)

View 1---View 2---View 3---View 4---View 5---View 6---View 7---View 8

Transaction Name		Date	
Message Template Name			
Receiver Role		Sender Role	
Name		Name	
Designation		Designation	
Organization		Organization	
Address		Address	
E-mail		E-mail	
Postal		Postal	
Phone		Phone	
Fax		Fax	
Cc (E-mail)		Acknowledgement	Select or type...
Bcc (E-mail)		Message Subject	
		Priority	Select or type...
		Attachment	Click here to attach a file

Project Name		Allocation Type	Select...
Project No.		Other, please specify	
Total Cost of Allocation	(Mil $)		

Tangible Capital Asset

Asset Class	Unit	Quantity	Facility Sector Last Interim/Final Progress Payment Cost (Mil $)	Contingency Cost (Mil $)	Total Cost (Mil $)	*For Disposal Only* Disposed Quantity	Installation Year
1.1 Police Protection							
Land	Sq.m						
Building	Each						
Equipment	Each						
Vehicle	Each						
Sub-Total			0	0	0		
1.2 Fire Protection							
Land	Sq.m						
Building	Each						
Equipment	Each						
Vehicle	Each						
Sub-Total			**0**	**0**	**0**		
2. Recreational and Culture Facility							
Park	Each						
Sport	Each						
Arena	Each						
Community Center	Each						
Senior Center	Each						
Heritage	Each						
Art Gallery	Each						
Performing Art	Each						
Tourist	Each						
Museum	Each						
Library	Each						
Sub-Total			**0**	**0**	**0**		
TOTAL			0	0	0		

Save and Exit | Save and Next

Figure K-12 Message template view 1 defined for atomic transaction 4, 6, and 7—submit TCA information, (facility sector assets)

Tangible Capital Asset Reporting (View 2)

View 1---**View 2**---View 3---View 4---View 5---View 6---View 7---View 8

Asset Class	Unit	Quantity	Last Interim/Final Progress Payment Cost (Mil $)	Contingency Cost (Mil $)	Total Cost (Mil $)	Disposed Quantity	Installation Year
		Transportation Infrastructure Sector				***For Disposal Only***	
1. Transportation Infrastructure							
1.1 Land Asset							
Road Right of Way	Sq.m						
Road Allowance	Sq.m						
Parking Lot	Sq.m						
Sub-Total			0	0	0		
1.2 Building Asset							
Transfer Station	Each						
Transit Workshop	Each						
Transit Garage	Each						
Parking Structure	Each						
Sub-Total			0	0	0		
1.3 Roads Assets							
Function based Roads							
Rural Local	Km						
Rural Collector	Km						
Rural Arterial	Km						
Rural Freeway	Km						
Sub-Total							
Urban Public Lane	Km						
Urban Local	Km						
Urban Collector	Km						
Urban Arterial	Km						
Urban Expressway	Km						
Urban Freeway	Km						
Sub-Total			0	0	0		
Material based Roads							
Dirt	Km						
Gravel	Km						
Concrete	Km						
Asphalt	Km						
Brick	Km						
Direction based Roads							
Undivided	Km						
Divided							
Two Lane Divided	Km						
Three Lane Divided	Km						
Four Lane Divided	Km						
Five Lane Divided	Km						
Six Lane Divided	Km						
Sub-Total			0	0	0		
1.4 Pathway Asset							
Alley	Lin.m						
Bike Cum Jogging	Lin.m						
Sidewalk							
Concrete	Lin.m						
Asphalt	Lin.m						
Brick	Lin.m						
Stone	Lin.m						
Sub-Total			0	0	0		

Tangible Capital Asset Reporting (View 2)

View 1---**View 2**---View 3---View 4---View 5---View 6---View 7---View 8

Asset Class	Unit	Quantity	Last Interim/Final Progress Payment Cost (Mil $)	Contingency Cost (Mil $)	Total Cost (Mil $)	Disposed Quantity	Installation Year
		Transportation Infrastructure Sector				*For Disposal Only*	
1.5 Median Asset							
Concrete	Lin.m						
Metal Beam	Lin.m						
Fence	Lin.m						
Sub-Total			0	0	0		
1.6 Shoulder Asset							
Concrete	Km						
Asphalt	Km						
Gravel	Km						
Brick	Km						
Sub-Total			0	0	0		
1.7 Curb Asset							
Curb	Lin.m						
Sub-Total							
1.8 Wall Asset							
Noise Wall	Lin.m						
Breast Wall	Lin.m						
Retaining Wall	Lin.m						
Sub-Total			0	0	0		
1.9 Guard Rail Asset							
Masonry	Lin.m						
Metal	Lin.m						
Concrete	Lin.m						
Sub-Total			0	0	0		
1.10 Street Light Transportation Asset							
Concrete Pole	Each						
Metal Pole	Each						
Timber Pole	Each						
Sub-Total			0	0	0		
1.11 Machinery and Equipment Transportation Asset							
Monitoring Equipment							
Computer Systems	Each						
Surveillance Camera	Each						
Traffic Camera	Each						
Regulatory Equipment							
Traffic Signal	Each						
Traffic Sign	Each						
Sub-Total			0	0	0		
1.12 Vehicle Transportation Asset							
Trolley Car	Each						
Para Transit	Each						
Transit Train	Each						
Transit Bus	Each						
Sub-Total			0	0	0		
TOTAL			0	0	0		

Back | Save and Exit | Save and Next

Figure K-13 Message template view 2 defined for atomic transaction 4, 6, and 7—submit TCA information, (road transportation sector assets)

Tangible Capital Asset Reporting (View 3)

View 1---View 2---**View 3**---View 4---View 5---View 6---View 7---View 8

Asset Class	Unit	Quantity	Last Interim/Final Progress Payment Cost (Mil $)	Contingency Cost (Mil $)	Total Cost (Mil $)	Disposed Quantity	Installation Year
		Infrastructure Sector				*For Disposal Only*	
1. Transportation Infrastructure							
1.13 Bridges Asset							
Superstructure Material based Bridges							
Steel	Each						
Masonry	Each						
Concrete	Each						
Function based Bridges							
Pedestrian	Each						
Vehicular	Each						
Superstructure Form based Bridges							
Slab	Each						
Truss	Each						
Arch	Each						
Suspension	Each						
Span Length based Bridges							
Minor	Each						
Major	Each						
Long Span	Each						
Sub-Total			**0**	**0**	**0**		
1.14 Tunnel Asset							
Single Tube	Each						
Twin Tube	Each						
Sub-Total			**0**	**0**	**0**		
TOTAL			0	0	0		

Back | Save and Exit | Save and Next

Figure K-14 Message template view 3 defined for atomic transaction 4, 6, and 7—submit TCA information, (bridge transportation sector assets)

Tangible Capital Asset Reporting (View 4)

View 1---View 2---View 3---**View 4**---View 5---View 6---View 7---View 8

		Water Sector Asset				*For Disposal Only*	
Asset Class	**Unit**	**Quantity**	**Last Interim/Final Progress Payment Cost (Mil $)**	**Contingency Cost (Mil $)**	**Total Cost (Mil $)**	**Disposed Quantity**	**Installation Year**
1. Water Asset							
1.1 Land Asset							
Right of Way Water Line	Sq.m						
Sub-Total							
1.2 Building Asset							
Pumping Station	Each						
Booster Station	Each						
Filtration Facility	Each						
Sub-Total			0	0	0		
1.3 Water Line Asset							
Hierarchical Water Line							
Mainline	Lin.m						
Serviceline	Lin.m						
Material Water Line							
Metallic	Lin.m						
Cement	Lin.m						
Plastic	Lin.m						
Sub-Total			0	0	0		
1.4 Tank	Each						
1.5 Valve Chamber	Each						
1.6 Well	Each						
1.7 Reservoir	Each						
Sub-Total			0	0	0		
1.8 Machinery and Equipment Asset							
Valve	Each						
Fire Hydrant	Each						
Meter	Each						
Pump	Each						
Filtration Plant	Each						
Sub-Total			0	0	0		
TOTAL			0	0	0		

Back | Save and Exit | Save and Next

Figure K-15 Message template view 4 defined for atomic transaction 4, 6, and 7—submit TCA information, (water sector assets)

Tangible Capital Asset Reporting (View 5)							
View 1---View 2---View 3---View 4---**View 5**---View 6---View 7---View 8							
		Wastewater Sector Asset				*For Disposal Only*	
Asset Class	**Unit**	**Quantity**	**Last Interim/Final Progress Payment Cost (Mil $)**	**Contingency Cost (Mil $)**	**Total Cost (Mil $)**	**Disposed Quantity**	**Installation Year**
1. Sanitary Wastewater Asset							
1.1 Land Asset							
Right of Way Sanitary Wastewater Line	Sq.m						
Sub-Total							
1.2 Building Asset							
Lift Station Building	Each						
Treatment Plant Building	Each						
Sub-Total			0	0	0		
1.3 Sanitary Wastewater Line Asset							
Hierarchical Sanitary WW Line							
Mainline	Lin.m						
Serviceline	Lin.m						
Material Sanitary WW Line							
Metallic	Lin.m						
Cement	Lin.m						
Plastic	Lin.m						
Sub-Total			0	0	0		
1.4 Manhole	Each						
1.5 Tank	Each						
Sub-Total			0	0	0		
1.6 Machinery and Equipment Asset							
Pump	Each						
Generator	Each						
Sub-Total							
TOTAL			0	0	0		
Back				Save and Exit			Save and Next

Figure K-16 Message template view 5 defined for atomic transaction 4, 6, and 7—submit TCA information, (sanitary wastewater sector assets)

Tangible Capital Asset Reporting (View 6)

View 1---View 2---View 3---View 4---View 5---**View 6**---View 7---View 8

		Wastewater Sector Asset				*For Disposal Only*	
Asset Class	**Unit**	**Quantity**	**Last Interim/Final Progress Payment Cost (Mil $)**	**Contingency Cost (Mil $)**	**Total Cost (Mil$)**	**Disposed Quantity**	**Installation Year**
1. Storm Wastewater Asset							
1.1 Land Asset							
Right of Way Storm Wastewater Line	Sq.m						
Sub-Total							
1.2 Building Asset							
Lift Station Building	Each						
Sub-Total							
1.3 Storm Wastewater Line Asset							
Hierarchical based Storm WW Line							
Main Line	Lin.m						
Service Line	Lin.m						
Form based Storm WW Line							
Channel	Lin.m						
Material based Storm WW Line							
Metallic	Lin.m						
Cement	Lin.m						
Plastic	Lin.m						
Sub-Total			**0**	**0**	**0**		
1.4 Dam Storm Wastewater Asset							
Earthen	Each						
Concrete	Each						
Sub-Total			**0**	**0**	**0**		
1.5 Culvert Storm Wastewater Asset							
Material based Culvert							
Concrete	Each						
Steel	Each						
Cast Iron	Each						
Plastic	Each						
Form based Culvert							
Pipe	Each						
Arch	Each						
Box	Each						
Slab	Each						
Sub-Total			**0**	**0**	**0**		
1.6 Pond	Each						
1.7 Dyke							
Earthen	Each						
Concrete	Each						
Sub-Total			**0**	**0**	**0**		
1.8 Machinery and Equipment Asset							
Pump	Each						
Sub-Total							
TOTAL			0	0	0		

Back | Save and Exit | Save and Next

Figure K-17 Message template view 6 defined for atomic transaction 4, 6, and 7—submit TCA information, (storm wastewater sector assets)

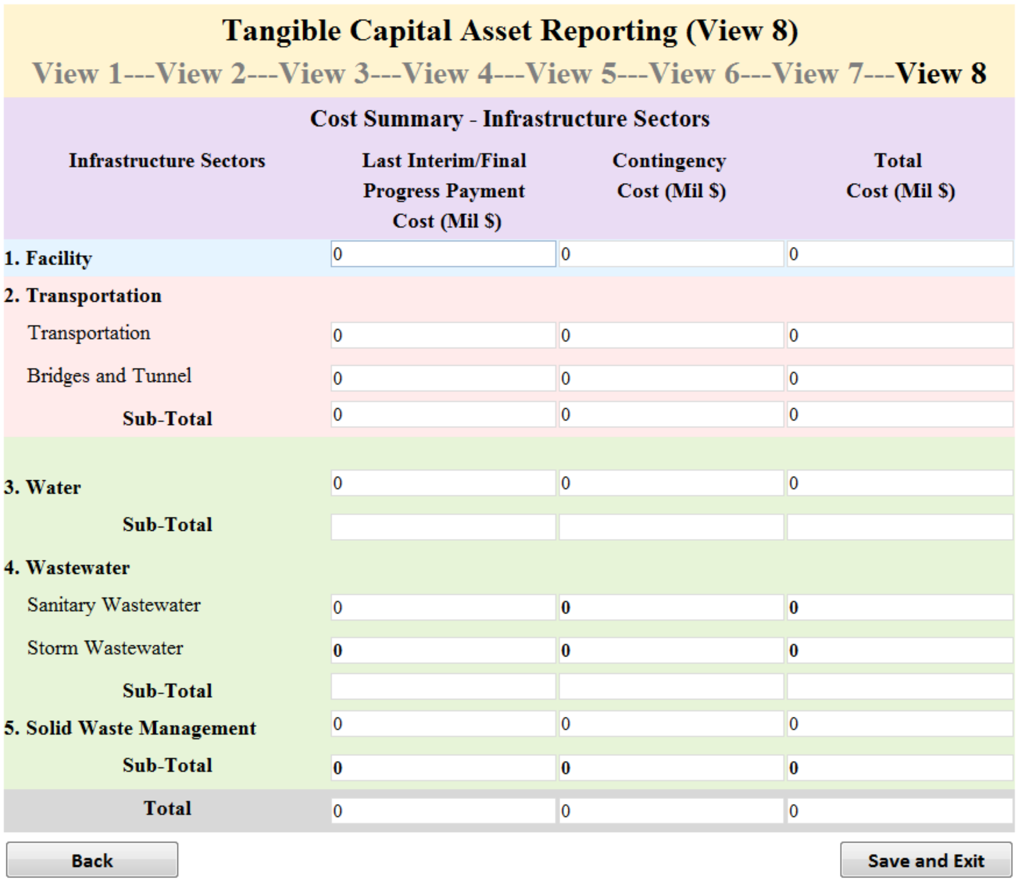
Tangible Capital Asset Reporting (View 7)

View 1---View 2---View 3---View 4---View 5---View 6---**View 7**---View 8

Asset Class	Unit	Quantity	Last Interim/Final Progress Payment Cost (Mil $)	Contingency Cost (Mil $)	Total Cost (Mil $)	Disposed Quantity	Installation Year
		Solidwaste Management Sector Asset				***For Disposal Only***	
1. Solidwaste Asset							
1.1 Land Asset							
Landfill	Sq.m						
Sub-Total							
1.2 Building Asset							
Recycling Building Facility	Each						
Sub-Total							
1.3 Machinery and Equipment Asset							
Recycling Equipment	Each						
1.4 Vehicle Asset							
Waste Disposal Vehicle	Each						
Sub-Total							
TOTAL			0	0	0		

Back | Save and Exit | Save and Next

Figure K-18 Message template view 7 defined atomic transaction 4, 6, and 7—submit TCA information, (solid waste management sector assets)



Tangible Capital Asset Reporting (View 8)

View 1---View 2---View 3---View 4---View 5---View 6---View 7---**View 8**

Cost Summary - Infrastructure Sectors

Infrastructure Sectors	Last Interim/Final Progress Payment Cost (Mil $)	Contingency Cost (Mil $)	Total Cost (Mil $)
1. Facility	0	0	0
2. Transportation			
Transportation	0	0	0
Bridges and Tunnel	0	0	0
Sub-Total	0	0	0
3. Water	0	0	0
Sub-Total			
4. Wastewater			
Sanitary Wastewater	0	**0**	**0**
Storm Wastewater	**0**	**0**	**0**
Sub-Total			
5. Solid Waste Management	0	0	0
Sub-Total	**0**	**0**	**0**
Total	0	0	0

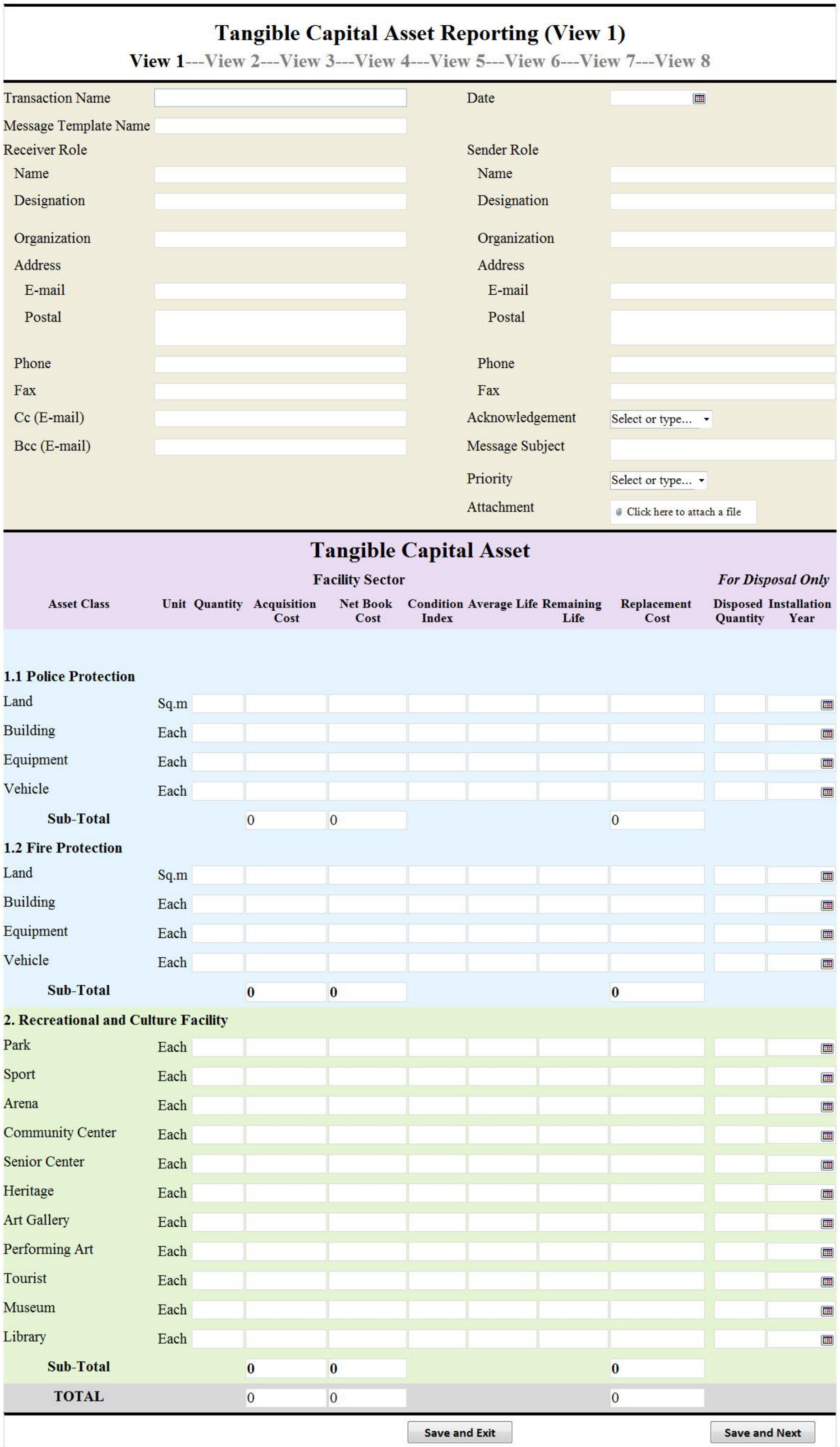
Back | Save and Exit

Figure K-19 Message template view 8 defined for atomic transaction 4, 6, and 7—submit TCA information, (sectoral cost summary)

Using this multi-view MT, the finance department receives the TCA information for all ongoing and completed projects in the current reporting year. The accountant reviews and records the TCA information received and discusses discrepancies; if any, with the manager finance. The manager finance then finally reviews the TCA information and sends it to the council and the provincial government via atomic transaction 8 and 9 as part of the reporting requirements. The MT designed for these atomic transactions represents the cumulative TCA information received for all projects. This MT was also designed as a generic multi-view MT that fulfills the reporting requirements of all different types of city, district, town, and village municipalities. While reporting the TCA information, the finance section should fill related applicable fields of the MT and leave others blank that are not applicable.

A generic multi-view MT was designed to send the TCA information to the council and the provincial government via atomic transaction 8 and 9. This MT has eight different views and each view represents the TCA information related to a specific infrastructure sector or sub-sector.

View 1 of this MT represents the TCA information in terms of different facilities (see Figure K-20). View 2 (see Figure K-21) shows road transportation assets and view 3 (see Figure K-22) shows bridge transportation assets. View 4 represents the water sector assets (see Figure K-23) while view 5 (see Figure K-24) and 6 (see Figure K-25) show the sanitary and storm wastewater assets respectively. View 7 shows the solid waste management assets (see Figure K-26) and view 8 represents the sectoral cost summary (see Figure K-27).



Tangible Capital Asset Reporting (View 1)

View 1---View 2---View 3---View 4---View 5---View 6---View 7---View 8

Transaction Name		Date	
Message Template Name			
Receiver Role		Sender Role	
Name		Name	
Designation		Designation	
Organization		Organization	
Address		Address	
E-mail		E-mail	
Postal		Postal	
Phone		Phone	
Fax		Fax	
Cc (E-mail)		Acknowledgement	Select or type...
Bcc (E-mail)		Message Subject	
		Priority	Select or type...
		Attachment	Click here to attach a file

Tangible Capital Asset

Facility Sector — ***For Disposal Only***

Asset Class	Unit	Quantity	Acquisition Cost	Net Book Cost	Condition Index	Average Life	Remaining Life	Replacement Cost	Disposed Quantity	Installation Year
1.1 Police Protection										
Land	Sq.m									
Building	Each									
Equipment	Each									
Vehicle	Each									
Sub-Total			0	0				0		
1.2 Fire Protection										
Land	Sq.m									
Building	Each									
Equipment	Each									
Vehicle	Each									
Sub-Total			**0**	**0**				**0**		
2. Recreational and Culture Facility										
Park	Each									
Sport	Each									
Arena	Each									
Community Center	Each									
Senior Center	Each									
Heritage	Each									
Art Gallery	Each									
Performing Art	Each									
Tourist	Each									
Museum	Each									
Library	Each									
Sub-Total			**0**	**0**				**0**		
TOTAL			0	0				0		

Save and Exit — Save and Next

Figure K-20 Message template view 1 defined for atomic transaction 8 and 9—send TCA information, (facility sector assets)

Tangible Capital Asset Reporting (View 2)

View 1---**View 2**---View 3---View 4---View 5---View 6---View 7---View 8

				Transportation Infrastructure Sector					*For Disposal Only*	
Asset Class	**Unit**	**Quantity**	**Acquisition Cost**	**Net Book Cost**	**Condition Index**	**Average Life**	**Remaining Life**	**Replacement Cost**	**Disposed Quantity**	**Installation Year**
1. Transportation Infrastructure										
1.1 Land Asset										
Road Right of Way	Sq.m									
Road Allowance	Sq.m									
Parking Lot	Sq.m									
Sub-Total			0	0				0		
1.2 Building Asset										
Transfer Station	Each									
Transit Workshop	Each									
Transit Garage	Each									
Parking Structure	Each									
Sub-Total			0	0				0		
1.3 Roads Assets										
Function based Roads										
Rural Local	Km									
Rural Collector	Km									
Rural Arterial	Km									
Rural Freeway	Km									
Sub-Total										
Urban Public Lane	Km									
Urban Local	Km									
Urban Collector	Km									
Urban Arterial	Km									
Urban Expressway	Km									
Urban Freeway	Km									
Sub-Total			0	0				0		
Material based Roads										
Dirt	Km									
Gravel	Km									
Concrete	Km									
Asphalt	Km									
Brick	Km									
Direction based Roads										
Undivided	Km									
Divided										
Two Lane Divided	Km									
Three Lane Divided	Km									
Four Lane Divided	Km									
Five Lane Divided	Km									
Six Lane Divided	Km									
Sub-Total			0	0				0		

Tangible Capital Asset Reporting (View 2)

View 1---**View 2**---View 3---View 4---View 5---View 6---View 7---View 8

Transportation Infrastructure Sector *For Disposal Only*

Asset Class	Unit	Quantity	Acquisition Cost	Net Book Cost	Condition Index	Average Life	Remaining Life	Replacement Cost	Disposed Quantity	Installation Year
1.4 Pathway Asset										
Alley	Lin.m									
Bike Cum Jogging	Lin.m									
Sidewalk										
Concrete	Lin.m									
Asphalt	Lin.m									
Brick	Lin.m									
Stone	Lin.m									
Sub-Total			0	0				0		
1.5 Median Asset										
Concrete	Lin.m									
Metal Beam	Lin.m									
Fence	Lin.m									
Sub-Total			0	0				0		
1.6 Shoulder Asset										
Asphalt	Km									
Concrete	Km									
Brick	Km									
Stone	Km									
Sub-Total			0	0				0		
1.7 Curb Asset										
Curb	Lin.m									
Sub-Total										
1.8 Wall Asset										
Noise Wall	Lin.m									
Breast Wall	Lin.m									
Retaining Wall	Lin.m									
Sub-Total			0	0				0		
1.9 Guard Rail Asset										
Masonry	Lin.m									
Metal	Lin.m									
Concrete	Lin.m									
Sub-Total			0	0				0		
1.10 Street Light Transportation Asset										
Concrete Pole	Each									
Metal Pole	Each									
Timber Pole	Each									
Sub-Total			0	0				0		
1.11 Machinery and Equipment Transportation Asset										
Monitoring Equipment										
Computer Systems	Each									
Surveillance Camera	Each									
Traffic Camera	Each									
Stone Parking Lot	Each									
Regulatory Equipment										
Traffic Signal	Each									
Traffic Sign*	Each									
Sub-Total			0	0				0		
1.12 Vehicle Transportation Asset										
Trolley Car	Each									
Para Transit	Each									
Bus	Each									
Train	Each									
Sub-Total			0	0				0		
TOTAL			0	0				0		

Back | Save and Exit | Save and Next

Figure K-21 Message template view 2 defined for atomic transaction 8 and 9—send TCA information, (road transportation sector assets)

Tangible Capital Asset Reporting (View 3)

View 1---View 2---**View 3**---View 4---View 5---View 6---View 7---View 8

Asset Class	Unit	Quantity	Acquisition Cost	Net Book Cost	Condition Index	Average Life	Remaining Life	Replacement Cost	Disposed Quantity	Installation Year
			Infrastructure Sector						*For Disposal Only*	
1. Transportation Infrastructure										
1.13 Bridges Asset										
Superstructure Material based Bridges										
Steel	Each									
Masonry	Each									
Concrete	Each									
Function based Bridges										
Pedestrian	Each									
Vehicular	Each									
Superstructure Form based Bridges										
Slab	Each									
Truss	Each									
Arch	Each									
Suspension	Each									
Span Length based Bridges										
Major	Each									
Minor	Each									
Long Span	Each									
Sub-Total			**0**	**0**				**0**		
1.14 Tunnel Asset										
Single Tube	Each									
Twin Tube										
Horizontal Twin Tube	Each									
Vertical Twin Tube	Each									
Sub-Total			**0**	**0**				**0**		
TOTAL			0	0				0		

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Figure K-22 Message template view 3 defined for atomic transaction 8 and 9—send TCA information, (bridge transportation sector assets)

Tangible Capital Asset Reporting (View 4)

View 1---View 2---View 3---**View 4**---View 5---View 6---View 7---View 8

Asset Class	Unit	Quantity	Acquisition Cost	Net Book Cost	Condition Index	Average Life	Remaining Life	Replacement Cost	Disposed Quantity	Installation Year
			Water Sector Asset						*For Disposal Only*	
1. Water Asset										
1.1 Land Asset										
Right of Way Water Line	Sq.m									
Sub-Total										
1.2 Building Asset										
Pumping Station	Each									
Booster Station	Each									
Filtration Facility										
Sub-Total			0	0				0		
1.3 Water Line Asset										
Hierarchical based Water Line										
Main Line	Lin.m									
Service Line	Lin.m									
Material based Water Line										
Metallic										
Cast Iron	Lin.m									
Galvanized Iron	Lin.m									
Galvanized Steel	Lin.m									
Steel	Lin.m									
Cement										
Concrete Cement	Lin.m									
Asbestos Cement	Lin.m									
Plastic										
Polyvinyl Chloride	Lin.m									
Chlorinated Polyvinyl Chloride	Lin.m									
Polyethylene	Lin.m									
High Density Polyethylene	Lin.m									
Sub-Total			0	0				0		
1.4 Tank	Each									
1.5 Valve Chamber	Each									
1.6 Wall	Each									
1.7 Reservoir	Each									
Sub-Total			0	0				0		
1.8 Machinery and Equipment Asset										
Valve	Each									
Fire Hydrant	Each									
Meter	Each									
Pump	Each									
Filtration Plant	Each									
Sub-Total			0	0				0		
TOTAL			0	0				0		

Back | Save and Exit | Save and Next

Figure K-23 Message template view 4 defined for atomic transaction 8 and 9—send TCA information, (water sector assets)

Tangible Capital Asset Reporting (View 5)

View 1---View 2---View 3---View 4---**View 5**---View 6---View 7---View 8

Asset Class	Unit	Quantity	Acquisition Cost	Net Book Cost	Condition Index	Average Life	Remaining Life	Replacement Cost	Disposed Quantity	Installation Year
			Wastewater Sector Asset						***For Disposal Only***	
1. Sanitary Wastewater Asset										
1.1 Land Asset										
Right of Way Sanitary Wastewater Line	Sq.m									
Sub-Total										
1.2 Building Asset										
Lift Station Building	Each									
Treatment Plant Building	Each									
Sub-Total			0	0				0		
1.3 Sanitary Wastewater Line Asset										
Hierarchical based Sanitary WW Line										
Main Line	Lin.m									
Service Line	Lin.m									
Material based Sanitary WW Line										
Metallic										
Ductile Iron	Lin.m									
Cast Iron	Lin.m									
Corrugated Aluminium	Lin.m									
Galvanized Steel	Lin.m									
Cement										
Vitrified Clay	Lin.m									
Concrete Cement	Lin.m									
Asbestos Cement	Lin.m									
Plastic										
Polyvinyl Chloride	Lin.m									
Acrylonitrile Butadiene Styrene	Lin.m									
Reinforced Plastic Mortar	Lin.m									
Polyethylene	Lin.m									
Polypropylene	Lin.m									
High Density Polyethylene	Lin.m									
Sub-Total			0	0				0		
1.4 Manhole	Each									
1.5 Tank Treatment Plant	Each									
Sub-Total			0	0				0		
1.6 Machinery and Equipment Asset										
Pump	Each									
Generator	Each									
Sub-Total										
TOTAL			0	0				0		

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Figure K-24 Message template view 5 defined for atomic transaction 8 and 9—send TCA information, (sanitary wastewater sector assets)

Tangible Capital Asset Reporting (View 6)

View 1---View 2---View 3---View 4---View 5---**View 6**---View 7---View 8

Asset Class	Unit	Quantity	Acquisition Cost	Net Book Cost	Condition Index	Average Life	Remaining Life	Replacement Cost	Disposed Quantity	Installation Year
		Wastewater Sector Asset							*For Disposal Only*	
1. Storm Wastewater Asset										
1.1 Land Asset										
Right of Way Storm Wastewater Line	Sq.m									
Sub-Total										
1.2 Building Asset										
Lift Station Building	Each									
Sub-Total										
1.3 Storm Wastewater Line Asset										
Hierarchical based Storm WW Line										
Main Line	Lin.m									
Service Line	Lin.m									
Form based Storm WW Line										
Channel	Lin.m									
Material based Storm WW Line										
Metallic	Lin.m									
Cement	Lin.m									
Plastic	Lin.m									
Sub-Total			**0**	**0**				**0**		
1.4 Dam Storm Wastewater Asset										
Earthen	Each									
Concrete	Each									
Sub-Total			**0**	**0**				**0**		
1.5 Culvert Storm Wastewater Asset										
Material based Culvert										
Concrete	Each									
Steel	Each									
Cast Iron	Each									
Plastic	Each									
Form based Culvert										
Pipe	Each									
Arch	Each									
Box	Each									
Slab	Each									
Sub-Total			**0**	**0**				**0**		
1.6 Pond	Each									
1.7 Dyke										
Earthen	Each									
Concrete	Each									
Sub-Total			**0**	**0**				**0**		
1.8 Machinery and Equipment Asset										
Pump	Each									
Sub-Total										
TOTAL			0	0				0		

Back | Save and Exit | Save and Next

Figure K-25 Message template view 6 defined for atomic transaction 8 and 9—send TCA information, (storm wastewater sector assets)

Tangible Capital Asset Reporting (View 7)

View 1---View 2---View 3---View 4---View 5---View 6---**View 7**---View 8

		Solidwaste Management Sector Asset							*For Disposal Only*	
Asset Class	**Unit**	**Quantity**	**Acquisition Cost**	**Net Book Cost**	**Condition Index**	**Average Life**	**Remaining Life**	**Replacement Cost**	**Disposed Quantity**	**Installation Year**
1. Solidwaste Asset										
1.1 Land Asset										
Landfill	Sq.m									
Sub-Total										
1.2 Building Asset										
Recycling Building Facility	Each									
Sub-Total										
1.3 Machinery and Equipment Asset										
Recycling Equipment	Each									
1.4 Vehicle Asset										
Waste Disposal Vehicle	Each									
Sub-Total										
TOTAL			0	0				0		

Back | Save and Exit | Save and Next

Figure K-26 message template view 7 defined for atomic transaction 8 and 9—send TCA information, (solid waste management sector assets)

Tangible Capital Asset Reporting (View 8)

View 1---View 2---View 3---View 4---View 5---View 6---View 7---**View 8**

Cost Summary - Infrastructure Sectors			
Infrastructure Sectors	**Acquisition Cost**	**Net Book Cost**	**Replacement Cost**
1. Facility	0	0	0
2. Transportation			
Transportation	0	0	0
Bridges and Tunnel	0	0	0
Sub-Total	0	0	0
3. Water	0	0	0
4. Wastewater			
Sanitary Wastewater	0	0	0
Storm Wastewater	0	0	0
Sub-Total			
5. Solid Waste Management	0	0	0
Sub-Total	0	0	0
Total	0	0	0

Back | Save and Exit

Figure K-27 Message template view 8 defined for atomic transaction 8 and 9—send TCA information, (sectoral cost summary)

K.1.6 Step 6—Review To-be Transaction Map and Message Templates

In this step, the To-be TM of the AI&CAR/TCA Reporting process and MTs designed for each atomic transaction were reviewed through the industry experts (i.e. respondents). The purpose of the review was to identify shortcomings; and propose improvements; if any, in the To-be TM and all MTs defined for the exchange of TCA information in each atomic transaction. The review of the To-be TM and MTs formalized for the AI&CAR/TCA process was conducted through an expert review survey. During survey, the experts (i.e. respondents) were provided with a questionnaire (attached at Appendix N) and were requested to answer all the questions reflected in the questionnaire.

K.1.6.1 Respondents Profile Information

Three experts (survey respondents) reviewed the To-be TM and MTs developed for the AI&CAR/TCA Reporting. The personal information of the respondents is kept confidential as per their request, whereas their technical information is presented in Table K-1.

Table K-1 Respondents profile information

S. No.	Information relating Respondent Profile			
A.	**Respondent General Profile**	**Respondent A**	**Respondent C**	**Respondent D**
1	Respondent Name	Kept Confidential	Kept Confidential	Kept Confidential
2	Respondent Position/Designation/Title			
3	Respondent Organization Name			
4	Respondent Tel No.			
5	Respondent E-mail Address			
B.	**Respondent Technical Profile**			
6	Years of Experience	38	18	17
7	Field/Sector of Experience	Highways and Infrastructure	Municipal and Transportation	Municipal and Civil Engineering

K.1.6.2 Familiarity with Infrastructure Sectors & Public Sector Accounting Board Reporting Requirements

The respondents' familiarity with different infrastructure sectors and PSAB-3150 reporting requirements is captured in Table K-2.

Table K-2 Familiarity with infrastructure sectors and PSAB reporting requirements

Respondents' Familiarity with Infrastructure Sectors and PSAB Reporting Requirements					
Familiarity Questions	**Respondents – A**	**Respondents – B**	**Respondents – C**	**Average Score**	**Legends**
	Agreement Rating				
Familiarity with Infrastructure Sectors					
Transportation	3	5	5	**4.33**	0 Unable to Rate
Water	4	4	4	**4.00**	1 Not at all Familiar
Wastewater	5	4	4	**4.33**	2 Slightly Familiar
Solidwaste Management	3	4	5	**4.00**	3 Somewhat Familiar
Familiarity with PSAB Reporting Requirements for Tangible Capital Assets					4 Moderately Familiar
Familiarity with PSAB - 3150 Reporting Reqs.	5	5	4	**4.67**	5 Extremely Familiar

The respondents recorded their responses on a familiarity scale of 1 (not at all familiar) to 5 (extremely familiar). An average response score was calculated for each sector, which indicates that the respondents were moderately familiar with four infrastructure sectors reflected in the Table K-2. Similarly, the respondents also recorded their familiarity with the Public Sector Board Accounting Board Reporting Requirements (PSAB-3150), on a scale of 1 to 5. The average familiarity score obtained was 4.67~5, which means the respondents were extremely familiar with PSAB reporting requirements.

K.1.6.3 Review of the To-be TM and MT Developed for the AI&CAR/TCA Reporting

A review of the To-be TM and MTs for AI&CAR/TCA was completed and a summary of the proposed changes is presented in Figure K-28. Some of the proposed modifications were incorporated while some were recommended for future improvements because these changes were context specific.

Step - 6 Review Transaction Map and Message Template	
General Admin Information	
Name of TM	$\text{tm}_{\text{to-be}}$_tca_reporting
Date Reviewed	23/07/2013
Change Log	
Technical Information	
Summary Information	
1. The To-be TM developed for the Asset Inventory Condition Assessment Reporting/Tangible Capital Asset (AI&CAR/TCA) Reporting is complete; however, it shows the scenario where a consultant submits the TCA information while there are situations where a private developer or municipality crews may submit the TCA information. The actor role needs to be explicitly specified so that accurate To-be TM could be developed to represent a specific scenario.	
2. Tyically, the PSAB data includes the historical cost of the TCA. To make this historical cost valid, it should also include the construction date, to be able to bring the cost into constant dollars. There is no place to put the year of construction. For example, a bridge built in 1913 for $1 million and on built in 2013 for $1 millions cannot add up to $2 million in assets. The 1913 cost has to be multiplied by the proper factor (RSMEANS) to bring it into constant dollars.	
3. The multi-view Message Templates (MTs) defined for the AI&CAR/TCA Reporting needs to include a set of rows in each view to capture the TCA information that a specific municipality own, operate, or manage and it is not represened in the defined MTs. For these TCAs, "other categories" class needs to include in each view of the multi-view MTs developed for the AI&CAR/TCA reporting.	

Figure K-28 Review To-be transaction map and message templates defined for the AI&CAR/TCA reporting—(filled form)

K.1.7 Step 7—Adopt and Implement Standard Transaction Agreement/Transaction Specification

Once the To-be TM and MT were revised and finalized incorporating proposed changes, these were ready to adopt or implement into software applications. The combination of the finalized To-be TM, MTs and all filled forms is referred to as standard transaction agreement or transaction specification. The transaction development personnel may opt to adopt and implement the defined AI&CAR/TCA transaction specification directly (i.e. As-is) or may choose to propose and incorporate some location specific changes before implementing into applications in a specific context. Some guidance on how to implement transaction specifications into applications is presented in Chapter 9.

K.1.8 Step 8—Monitor Standard Transaction Agreements/Transaction Specification

In this step, the implemented transaction specifications are monitored for continuous improvement. This step has not yet been initiated for the proposed AI&CAR/TCA Reporting transaction specification as it is a newly defined specification, which will be monitored after being implemented in the prototype AIIS. A monitoring form has already been developed that guides the transaction development personnel on how to monitor an implemented transaction specification. The form for transaction monitoring is explained in detail previously in Chapter 7.

Appendix L Analysis of Variance, Transaction Formalism Protocol Verification

L.1 Analysis of Variance Single Factor Test for Transaction Formalism Protocol

The ANOVA single-factor technique was used to assess that there is a significant difference the score obtained by the proposed Transaction Formalism Protocol (TFP) developed as part of this research work and other existing methodologies and standards in the AEC/FM and other industries. The statistical analysis was conducted to compare the total score obtained by a methodology or standard against the maximum average score for a fully satisfied criterion represented by "+". The total score represents the total number of "+" for fully satisfied, "-" for partially satisfied/not entirely clear, and "x" for not satisfied as shown in Table L-1. For instance, a score of 5 under the column " Fully Satisfied" for the Information Delivery Manual means that the given standard has fully satisfied 5 out of 10 evaluation criteria described under the evaluation section of the Chapter 6.

Table L-1 Methodologies and standards evaluation result

Methodologies/ Standards	Fully Satisfied	Partially Satisfied	Not Satisfied	Max Avg. Score
AEC/FM				
Information Delivery Manual	5	4	1	10
Model View Definition	2	5	3	10
VISI	5	3	2	10
COIN	3	3	4	10
Proposed TFP Specification	10	0	0	10
Sub-Total	**25**	**15**	**10**	**50**
Non-AEC/FM				
UMM	7	3	0	10
ebXML	6	2	2	10
RossettaNet	5	3	2	10
Villarreal	5	3	2	10
Kim	1	2	7	10
Kramler	3	3	4	10
Bauer	4	1	5	10
Koehler	2	2	6	10
Sub-Total	**33**	**19**	**28**	**80**

The ANOVA single factor was selected for the analysis of the given data set because only one variable (i.e. methodology, standards, protocol) was compared. In the analysis, a value of 0.05 was used for the alpha factor "p", which means that the analysis was conducted at a confidence level of 95%. The null hypothesis states that there is no statistical difference between the score obtained by different methodologies against the maximum average score for a fully satisfied criterion. The result of the ANOVA single-factor is presented in Table L-2. The analysis results show a significant difference because the value of “F” is greater than “F_{crit}” (59.70>4.30) with p-value 1.05 x e^{-07} less than the alpha factor 0.050 (95% confidence level), indicating that the null hypothesis is to be rejected and that there is a significant difference between the score obtained by different methodologies against the maximum average score for a fully satisfied criterion.

Table L-2 ANOVA single-factor test result for methodologies and standards evaluation

	Anova: Single Factor					
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	187.041667	1	187.041667	59.7085852	1.0451E-07	4.3009495
Within Groups	68.9166667	22	3.13257576			
Total	255.958333	23				

Appendix M Transaction Formalism Protocol Validation

M.1 Transaction Formalism Protocol Tool Validation

The evaluation of the protocol was done at two levels. TFP verification and TFP validation. The TFP verification was carried out for the TFP Specification whereas the TFP validation was done for the TFP Tool, which is discussed in this section. The validation was done through experts using a structured questionnaire (attached at Appendix O). There were six sections in the questionnaire with section 1 and 2 describes the respondents (experts) profile information and familiarity with infrastructure sectors, data, process, and transaction modeling. The section 3, 4, 5, and 6 captures questions related to the TFP Tool validation assessment criteria; feasibility, usability, usefulness, and generalizeability, respectively. The questionnaire was presented to five respondents and were asked to reply to all questions. A brief summary of the TFP Tool validation is as follows.

M.1.1 Respondents Profile Information

The profile of the five experts who have participated in the validation of the TFP Tool is presented Table M-1. The respondents' general information is kept confidential as per their request, whereas the technical information are shown in the Table M-1. All of the experts have a rich experience in various civil engineering fields. The experts diverse experience makes them a good fit to evaluate the TFP Tool from different perspectives.

Table M-1 Respondents profile information

S. No.	Information relating Respondent Profile					
A.	**Respondent General Profile**	**Respondent A**	**Respondent B**	**Respondent C**	**Respondent D**	**Respondent E**
1	Respondent Name	Kept Confidential	Kept Confidential	Kept Confidential	Kept Confidential	Kept Confidential
2	Respondent Position/Designation/Title					
3	Respondent Organization Name					
4	Respondent Tel No.					
5	Respondent E-mail Address					
B.	**Respondent Technical Profile**					
6	Years of Experience	15 Years	7 Years	18	17	15+
7	Field/Sector of Experience	Highways and Infrastructure	Architecture and Construction	Municipal and Transportation	Municipal and Civil Engineering	Construction and Project Management

M.1.2 Respondents Familiarity with Infrastructure Sectors; and Data, Process, Transaction Modeling

The respondents (experts) familiarity with different infrastructure sectors; and data, process and transaction modeling are presented in Table M-2. The respondent's familiarity was assessed on a scale 1 (not at all familiar) to 5 (extremely familiar). The average score ranged from 3.80~4 (moderately familiar) to 4.8~5 (extremely familiar), which means the respondents were moderately familiar with the four infrastructure sectors. Within the different infrastructure sector, many of the respondents were more familiar with the transportation sector in comparison to other sectors. The reasons could be attributed to their background knowledge (degree) and experience relevant to the transportation sector.

Table M-2 Respondents' familiarity with infrastructure sectors; and data, process, and transaction modeling

Respondents Familiarity with Infrastructure Sectors and Data, Process, and Transaction Modeling							
Familiarity Questions	**Respondents**					**Average Score**	**Legends**
	A	**B**	**C**	**D**	**E**		
	Agreement Rating						
Familiarity with Infrastructure Sectors							
Transportation	5	4	5	5	5	**4.80**	0 Unable to Rate
Water	4	4	4	4	4	**4.00**	1 Not at all Familiar
Wastewater	4	4	4	4	3	**3.80**	2 Slightly Familiar
Solidwaste Management	4	3	4	5	3	**3.80**	3 Somewhat Familiar
Familiarity with Data, Process, and Transaction Modeling							4 Moderately Familiar
Data Modeling	4	4	4	4	4	**4.00**	5 Extremely Familiar
Process Modeling	4	4	4	4	4	**4.00**	
Transaction Modeling	4	3	4	4	3	**3.60**	

Similarly, the respondents' familiarity with the data modeling, process, modeling, and transaction modeling was assessed on a scale of 1 to 5. The average score ranged from 3.60 to 4, which means they were moderately familiar with data, process, and transaction modeling. None of the respondents reported extreme familiarity because it was not their primary job description; however, they knew the modeling concepts and were actively involved in the process and transaction modeling.

M.1.3 Transaction Formalism Protocol Feasibility

The feasibility of the proposed TFP Tool was assessed using three questions presented in Table M-3. The questions were developed based on three measures; completeness, rightness, and reasonableness. Each question was assessed on a scale of 1 (strongly disagree) to 5 (strongly agree). For completeness, rightness, and reasonableness, the average score was; 4.40~4 (agree), 4.60~5, and 4.8~5 (strongly agree) respectively. The average score indicates that the respondents were in general agreement on the quality (with regards to feasibility) of the proposed TFP Tool.

The results of the evaluation were also statistically analyzed using analysis of variance (ANOVA) two-factor without replication technique. In the analysis, an alpha or "p" value of "0.5" was assumed, which means the data was analyzed at 95% confidence level. The same ANOVA techniques and input parameters (assumptions) were used to test the statistical significance of the response recorded for usability and usefulness of the proposed TFP Tool. The null hypothesis states that there is no significant difference between the responses recorded for each question and; therefore, the respondents are in universal agreement on the feasibility of the TFP Tool.

Table M-3 Transaction formalism protocol feasibility

Transaction Formalism Protocol Feasibility							
	Respondents					Average Score	Legends
	A	B	C	D	E		
Questions	Agreement Rating						
Completeness: Does the TFP tool incorporate all the steps required for the design/improvement, implementation, and management of transactions?	5	4	4	5	4	**4.40**	0 Unable to Rate 1 Strongly Disagree 2 Disagree 3 Neither Agree nor Disagree 4 Agree 5 Strongly Agree
Rightness: Are the steps of the TFP tool right?	5	4	5	5	4	**4.60**	
Reasonableness: Are the steps of theTFP tool reasonable?	5	5	5	4	5	**4.80**	

The results of the statistical analysis are presented in Table M-4 wherein the value of “F < Fcri” (0.82 < 3.83), and the value of “p > α” (0.54 > 0.05). The results indicate that the there is no significant difference between the recorded responses and the null hypothesis is to be accepted. This proves statistically that the respondents were in universal agreement on the feasibility of the protocol.

Table M-4 ANOVA two-factor without replication test result for transaction formalism protocol feasibility

	Anova: Two-Factor Without Replication					
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Rows	0.4	2	0.2	0.70588235	0.52200625	4.45897011
Columns	0.93333333	4	0.23333333	0.82352941	0.54543477	3.83785335
Error	2.26666667	8	0.28333333			
Total	3.6	14				

M.1.4 Transaction Formalism Protocol Usability

The TFP Tool was validated for usability based on the three measures: understandability, applicability, and guidance/supportability. A question was developed for each of measure and respondents were asked to answer the questions through recording their response on an agreement scale of 1 (strongly disagree) to 5 (strongly agree). A response for each question was recorded as shown in Table M-5 and an average score was calculated. The average score for understandability, applicability, and guidance/supportability was 4.80~5 (strongly agree), 4.40~4 (agree), and 4.60~5 (strongly agree), respectively. The results indicate that the respondents were in general agreement on the Usability of the proposed TFP Tool.

Table M-5 Transaction formalism protocol usability

Transaction Formalism Protocol Usability							
Questions	Respondents Agreement Rating					Average Score	Legends
	A	B	C	D	E		
Understandability: Is the TFP tool easy to understand?	5	4	5	5	5	**4.80**	0 Unable to Rate 1 Strongly Disagree 2 Disagree 3 Neither Agree nor Disagree 4 Agree 5 Strongly Agree
Applicability: Is the TFP tool easy to apply while defining transactions?	5	4	4	5	4	**4.40**	
Guidance/Supportability: Does the TFP tool provide sufficient guidance on how to fill various sections of the forms?	5	4	4	5	5	**4.60**	

Similarly, the data recorded for Usability was tested for statistical significance using ANOVA two-factor without replication techniques. The null hypothesis states that there is no statistical significance between the responses recorded for understandability, applicability, and guidance/supportability of the TFP Tool. The statistical analysis results are shown in Table M-6, which indicates that "F < Fcri" (1.42 < 3.83), and the value of "p > α" (0.30 > 0.05), which means that the null hypothesis is to be accepted and there is no significant difference between the responses recorded for three quality criteria and the respondents were in universal agreement on the Usability of the TFP Tool.

Table M-6 ANOVA two-factor without replication test result for transaction formalism protocol usability

	Anova: Two-Factor Without Replication					
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Rows	0.13333333	2	0.06666667	0.28571429	0.75883457	4.45897011
Columns	1.33333333	4	0.33333333	1.42857143	0.30877058	3.83785335
Error	1.86666667	8	0.23333333			
Total	3.33333333	14				

M.1.5 Transaction Formalism Protocol Usefulness

The usefulness of the protocol was assessed based on five measures: effectiveness, efficiency, consistency, changeability/adaptability/customizability, and reusability. For each of these measures, a question was developed as shown the Table M-7. The respondents were asked to furnish their agreement on an agreement scale of 1 (strongly disagree) to 5 (strongly agree). Their responses were recorded and an average score was calculated for effectiveness, efficiency, consistency, changeability/adaptability/customizability, and reusability as 4.40~4, 4.60~5, 4.40~4, 4.00, and 4.60~5, respectively. The average score ranged from 4 (agree) to 5 (strongly agree), which means the respondents were in general agreement on the usefulness of the TFP Tool.

Table M-7 Transaction formalism protocol usefulness

Transaction Formalism Protocol Usefulness							
Questions	Respondents					Average Score	Legends
	A	B	C	D	E		
	Agreement Rating						
Effectiveness: Do you feel that the use of the TFP tool produce useful and effective results?	4	5	4	5	4	**4.40**	0 Unable to Rate 1 Strongly Disagree 2 Disagree 3 Neither Agree nor Disagree 4 Agree 5 Strongly Agree
Efficiency: Does the use of the TFP tool save you time and cost compared to defining transactions without using the proposed TFP tool?	5	4	5	4	5	**4.60**	
Consistency: Does the use of the TFP tool result in the creation of consistent transactions that are easily implementable in a variety of applications?	5	4	5	5	3	**4.40**	
Changeability/Adaptability: Does the use of the TFP tool result in the creation of transactions that are easily modifiable with changing requirements?	4	3	5	5	3	**4.00**	
Reuseability: Does the use of the TFP tool result in the creation/development of reuseable transactions?	4	4	5	5	5	**4.60**	

Similarly, statistical analysis of the expert review data was done to test the data for statistical significance. The result of the data is shown in Table M-8. As per the results, the value "F < Fcri" (1.68 < 3.00), and the value of "p > α" (0.20 > 0.05), which indicate that there is no significance between the responses of different respondents and the null hypothesis is to be accepted. The overall interpretation of the results emphasizes that the respondents were in universal agreement on the usefulness of the TFP Tool.

Table M-8 ANOVA two-factor without replication test result for transaction formalism protocol usefulness

	Anova: Two-Factor Without Replication					
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Rows	1.2	4	0.3	0.63157895	0.64711656	3.00691728
Columns	3.2	4	0.8	1.68421053	0.2026732	3.00691728
Error	7.6	16	0.475			
Total	12	24				

M.1.6 Transaction Formalism Protocol Generalizability

The proposed TFP Tool was also evaluated for generalizability using the generality measure. A question was developed as shown in Table M-9 to validate the protocol for generality. The experts were asked to record their responses on an agreement scale of 1 (strongly disagree) to 5 (strongly agree). The result of the expert review ranged from 4 (agree) to 5 (strongly agree). An average score was calculated, which was found to be 4.40~4 (agree) for generality, indicating that the respondents (experts) were in general agreement on the generality of the proposed TFP Tool and that the Tool can be applied to formalize diverse communications in the AEC/FM and other industries.

Table M-9 Transaction formalism protocol generalizability

Transaction Formalism Protocol Generalizability							
	Respondents					**Average Score**	**Legends**
	A	**B**	**C**	**D**	**E**		
Questions	**Agreement Rating**						
Generality: Is the proposed TFP applicable to formalize diverse communications in the AEC/FM and non-AEC/FM industries?	4	5	5	4	4	**4.40**	0 Unable to Rate 1 Strongly Disagree 2 Disagree 3 Neither Agree nor Disagree 4 Agree 5 Strongly Agree

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Appendix N Transaction Map/Message Template Review Questionnaire

Expert Review Survey to Review and Evaluate Transaction Map and Message Templates Defined for the Asset Inventory and Condition Assessment Reporting/ Tangible Capital Asset Reporting

SURVEY BACKGROUND INFORMATION, OBJECTIVES,

RESPONDENT CONSENT INFORMATION

&

QUESTIONNAIRE

Investigators:

Thomas Froese—Professor (Supervisor)

Jehan Zeb—Ph.D. Candidate (Investigator)

Expert Review Survey to Review and Evaluate Transaction Map and Message Templates Defined for the Asset Inventory and Condition Assessment Reporting/Tangible Capital Asset Reporting

Introduction

The Transaction Formalism Protocol (TFP) is an eight-step procedure developed as part of this research work to assist transaction development personnel (including transaction analysts, transaction designers, software developers, process modelers, and industry experts) to define transactions that have the greatest potential for IT improvements. The TFP is applied in the domain of infrastructure management to define the Asset Inventory and Condition Assessment Reporting AI&CAR process (i.e. Tangible Capital Asset reporting - TCA reporting) between the provincial and municipal government that is to be implemented in the Asset Information Integrator System (AIIS) to be developed as part of this research work. Prior to implementing into a software application, the formalized To-be Transaction Map (To-be TM) and Message Templates (MTs) defined for the AI&CAR/TCA Reporting are reviewed and evaluated as a separate distinct step in the proposed TFP to identify shortcomings; if any.

Purpose of the Expert Review Survey

The purpose of this survey is to review and validate the To-be TM of the AI&CAR/TCA Reporting and the information that is represented in the formalized MTs. The To-be TM of the AI&CAR/TCA Reporting and MTs are reviewed through industry experts to identify shortcomings and propose changes; if any. The main purpose is to refine and agree on the To-be TM of the AI&CAR/TCA Reporting process and the information content represented in the MTs.

Description of the Survey

Title: Expert Review Survey to Review and Evaluate Transaction Map and Message Templates Defined for Asset Inventory and Condition Assessment Reporting/Tangible Capital Asset Reporting

Supervisor: Professor, Thomas Froese

Department of Civil Engineering, (UBC)

2002-6250 Applied Science Lane, Vancouver, BC, V6T 1Z4

Investigator and Interviewer: Jehan Zeb, Graduate Research Assistant

Department of Civil Engineering, (UBC)

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Role of Respondents

The survey respondents are expected to have experience in one of the infrastructure sectors (transportation, water, wastewater, solid waste management), and Public Sector Accounting Board (PSAB-3150) reporting requirements. As a respondent, you are required to attend all the three sessions of the interview: introduction (15-20 minutes), comprehension (30-40 minutes), and execution (45-60 minutes). *Introduction session*—in this session, the purpose of the survey, the proposed TFP, and the review form developed as part of this research work will be briefly introduced. *Comprehension session*—in this session, review form and the AI&CAR/TCA Reporting process will be discussed in detail to have a clear understanding of the process and the elements presented in the form. *Execution session*—in this session, respondents are required to answer questions contained in Section 1 to 4 of the questionnaire. As part of the questionnaire, the defined To-be TM and MTs defined for the AI&CAR/TCA Reporting will be presented to the respondents for review. As a respondent, you are required to review and evaluate the To-be TM and the MTs defined for the AI&CAR/TCA Reporting. The whole interview process is expected to be completed from 1.5 to 2 hrs.

Use of Information and Procedure Adopted for Data Confidentiality

All the questions presented in the questionnaire are optional. The review data will be viewed and used by everyone associated with the design, implementation, and management of transactions in the domain of infrastructure management. The review data collected is to be used to refine the already defined To-be TM and MTs for the AI&CAR/TCA Reporting transaction. Please do not provide information that is confidential or of a sensitive nature. The information provided will only be used to achieve objectives of this research work only. Please inform us if you do not wish to publish your personal information and that of your organization.

Questions and Additional Information

A questionnaire and a review form will be used to collect information from the experts during the interview; therefore, most of the questions will be dealt with during the interview. However, any question or additional information can be asked from the supervisor or investigator at above-mentioned addresses.

Risks and its Remedial Measures

None of the risks; such as, breach of confidentiality, social stigmatization, threats to reputation, and psychological harm are anticipated for this research work. Therefore, it is requested not to provide any information that you deem is confidential or of a sensitive nature.

Respondent Rights

You are free to decline to participate and withdraw from the study at any time with no consequences. Please withhold any information that you do not wish to provide. If you have any concerns about your treatment of rights as a research respondent, you may call the Research Subject Information Line at (604) 822 8598, located in the UBC Office of Research Services at the University of British Columbia.

Potential Conflicts of Interest

This survey relates to reviewing the To-be TM and MTs defined for the AI&CAR/TCA Reporting process; therefore, no conflict of interest is anticipated between you or your organization and the researcher.

Questionnaire

The questionnaire is to be presented to the respondents during the interview. The questionnaire is divided into following four sections comprising:

Section—1: Respondent profile information

Section—2: Familiarity with infrastructure sectors and PSAB-3150 reporting requirements

Section—3: Review of To-be transaction map for the asset inventory and condition assessment reporting/tangible capital asset reporting

Section—4: Review of message templates for the asset inventory and condition assessment reporting/tangible capital asset reporting

Appendix—1: Message templates defined for all atomic transactions of the asset inventory and condition assessment reporting/tangible capital asset reporting

QUESTIONNAIRE

Definitions of the words in the questionnaire with bold, italic, and underline are defined in the glossary of terms at the end of this document.

Section 1: Respondent Profile Information

This section captures general and technical profile information of the respondents.

Please fill out the following respondent profile information in Table 1-1.

S. No.	Table 1-1 Information relating Respondent Profile	
A.	**Respondent General Profile**	
1	Respondent Name	
2	Respondent Position/Designation/Title	
3	Respondent Organization Name	
4	Respondent Tel No.	
5	Respondent E-mail Address	
B.	**Respondent Technical Profile**	
6	Years of Experience	
7	Field/Sector of Experience	

☐ Please check if you would like us to withhold your name and that of your organization from publication.

Date interview survey conducted: **/dd** **/MM** **/YYYY**

Section 2: Familiarity with Infrastructure Sectors and ***Data Modeling***

2.1 What is your level of familiarity with the following infrastructure sectors? Please select one familiarity level for each infrastructure sector in Table 2-1.

Table 2-1 Familiarity with Infrastructure Sector

	Familiarity Level					
	Unable to Rate	Not at all Familiar	Slightly Familiar	Somewhat Familiar	Moderately Familiar	Extremely Familiar
Infrastructure Sectors	0	1	2	3	4	5
1. Transportation						
2. Water						
3. Wastewater						
4. Solidwaste Management						

2.2 What is your level of familiarity with the Public Sector Accounting Board (PSAB-3150) reporting requirements for ***Tangible Capital Assets***? Please select your level of familiarity in Table 2-2.

Table 2-2 Familiarity with Public Sector Accounting Board Accounting Reporting Requirements

Unable to Rate	Not at all Familiar	Slightly Familiar	Somewhat Familiar	Moderately Familiar	Extremely Familiar
0	1	2	3	4	5

Section 3: To-be Transaction Map Review

3.1 The following Figure 3-1 shows the ***To-be transaction map*** for the ***AI&CAR/Tangible Capital Asset Reporting*** between the provincial and municipal governments. Do you think the ***AI&CAR/TCA Reporting*** transaction shown in Figure 3-1 is defined correctly? If not, what shortcomings or modifications you propose in light of the To-be transaction performance and other requirements: location, contractual, user exchange, design, regulatory, and security requirements. Please propose changes; if any, in Figure 3-2.

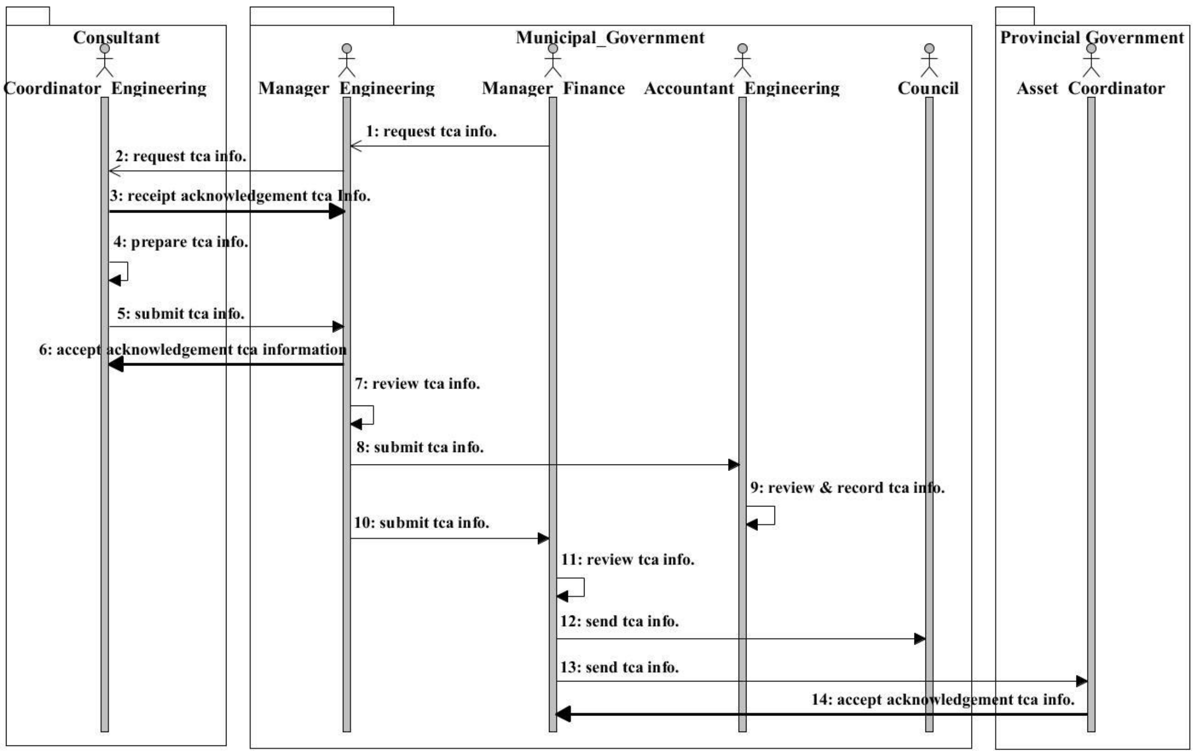

Figure 3-1 To-be transaction map for the asset inventory and condition assessment reporting/tangible capital asset reporting

Review of To-be Transaction Map **NOTE: Apply "√" for Yes and "x" for No in the change required column**		
Name of Atomic Transaction	**Change Req.**	**Description of Proposed Changes, if any.**

Figure 3-2 Review To-be transaction map for the asset inventory and condition assessment reporting/tangible capital asset reporting

Section 4: ***Message Template*** Review

4.1 ***Message templates*** are defined for each ***atomic transaction*** of the ***AI&CAR/TCA Reporting*** process between the provincial and municipal government. The complete set of defined MTs for the AI&CAR/TCA Reporting process is at Appendix—1 (see Figure K10 to Figure K27). Please review the formalized MTs and record your observations in the following Figure 4-1.

NOTE: The information attached to the questionnaire in Appendix–1 is re-organized in the thesis to avoid duplication. The content attached at Appendix—1 of the questionnaire is now placed at Appendix K of the thesis (see Figure K10 to Figure K27).

Review of Message Templates **NOTE: Apply "√" for Compliance, "x" Non-Compliance, and "-" for Not Applicable**										
Name of Atomic Transaction	**Sender Role**	**Receiver Role**	**Formatting Req.**	**Design Req.**						
	From	**To**	**Design Req.**	**Location Req.**	**Contract-ual Req.**	**Exchnage Req.**	**Regulatory Req.**	**Security Req.**	**To-be Transaction Performance**	**Others, if any.**
Proposed Changes/Revisions, if any.										

Figure 4-1 Review message templates for asset inventory and condition assessment reporting/tangible capital asset reporting

4.2 Please write a consolidated review of the To-be TM and defined MTs for the AI&CAR/TCA Reporting process in the Figure 4-2.

Step - 6 Review Transaction Map and Message Template	
General Admin Information	
Name of TM	
Date Reviewed	
Change Log	
Technical Information	
Summary Information	

Figure 4-2 Review summary information

Expert Review Survey to Review and Evaluate Transaction Map and Message Templates Defined for the Asset Inventory and Condition Assessment Reporting/Tangible Capital Asset Reporting

Glossary of Items

1. Atomic Transaction

Atomic transaction is a solo communication between collaborating parties that results in the transfer of information from one party to the other.

2. Data Modeling

Data modeling is the process of identifying entities, the relationship between those entities and their attributes. Data modeling is a method used to define and analyze data requirements needed to support the business processes of an organization.

3. Message

The message refers to the information formulated intangible (written) and intangible (verbal and non-verbal) forms that is exchanged between collaborating parties.

4. Message Template

Message template represents the information formulated in a tangible (written) form.

5. Tangible Capital Asset

Tangible capital assets are non-financial assets having physical substance that are acquired, constructed, or developed and: are held for use in the production or supply of goods and services; have useful lives extending beyond an accounting period; are intended to be used on a continuing basis, and are not intended for sale in the ordinary course of operations.

6. Tangible Capital Asset Reporting

Tangible capital asset reporting refers to the process in which different municipalities send asses inventory and condition assessment information to the provincial government for financial planning and budget allocations.

7. To-be Transaction Map

A To-be transaction map is an improved way of doing business and it should have at least one of the three improvements, including; process, information, and mode improvements.

8. Transaction

Any exchange of information, communication, or interaction between different parties that make up the information flow can be described as a transaction.

9. Transaction Map

Transaction map represents the number and sequence of atomic transactions in a given transaction.

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Appendix O Transaction Formalism Protocol Validation Questionnaire

Expert Review Survey Towards Transaction Formalism Protocol Validation

SURVEY BACKGROUND INFORMATION, OBJECTIVES,

RESPONDENT CONSENT INFORMATION

&

QUESTIONNAIRE

Investigators:

Thomas Froese—Professor (Supervisor)

Jehan Zeb—Ph.D. Candidate (Investigator)

Transaction Formalism Protocol Evaluation

Expert Review Survey Towards Transaction Formalism Protocol Validation

Introduction

Effective communication is vital, specifically in the domain of infrastructure management because citizen's livelihood greatly depends on it. To manage infrastructure systems, infrastructure organizations require data exchanges between diversified stakeholders. Presently, these data exchanges are accomplished on a manual and *ad hoc* basis. The growing trend is to transform current manual communications to a well-structured computer-to-computer based exchange of information. The issue is how to define these communications referred to as transactions. Currently, there exist certain methodologies or standards for process and communication formalism; however, it doesn't meet all of the objectives that the researchers are striving for in a step-by-step procedure for creating formal standard transaction agreements (known as transaction specifications) in the infrastructure industry. Most of the methodologies are process-centric, often focusing on work processes rather than communications. Most do not address modeling of the information describing the communication or contained within the communication, and they are not developed in a form suitable for end users that may not be ICT experts (e.g. explicit step-by-step procedures or a form-based TFP Tool). To address this issue, an ontology-supported Transaction Formalism Protocol (TFP) is developed that the transaction development personnel will use to formalize transactions in the domain of infrastructure management. The TFP is an eight-step procedure developed as part of this research work to assist transaction development personnel (transaction analysts, transaction designers, software developers, process modelers, and industry experts) to define transactions that have the greatest potential for IT improvements, effectively, efficiently, and consistently. The TFP is developed at two levels of abstraction: the TFP Specification and TFP Tool. The TFP Specification describes the protocol from a theoretical perspective, whereas the TFP Tool describes the protocol from a practical perspective, i.e. how transaction development personnel will use the protocol in an application context. The TFP Tool comprised of a set of forms and guidance developed for the proposed protocol. The main aim of this survey is to validate the proposed TFP.

Purpose of the Expert Review Survey

There are two objectives of this survey: (i) identify shortcomings; if any, and propose modifications to the TFP Tool; and (ii) validate the proposed TFP Tool based on a set of criteria: feasibility, usability, usefulness, and generalizability. The goal is to refine the content of the TFP Tool and evaluate the proposed TFP Tool for feasibility, usability, usefulness, and generalizability.

Description of the Survey

Title: Expert Review Survey Towards Transaction Formalism Protocol Validation

Supervisor: Professor, Thomas Froese

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2002-6250 Applied Science Lane, Vancouver, B.C, V6T 1Z4

Investigator and Interviewer: Jehan Zeb, Graduate Research Assistant

Department of Civil Engineering, (UBC)

2002-6250 Applied Science Lane, Vancouver, B.C, V6T 1Z4

Role of Respondents

The survey respondents are the transaction analysts, transaction designers, software developers, process modelers, and/or industry experts in the domain of infrastructure management. The industry experts are expected to have experience in one of the infrastructure sectors; transportation, water, wastewater, and solid waste management; and data modeling, transaction design, process modeling, etc. Respondents having experience in either asset management, or data modeling, process modeling, and transaction modeling are equally important; however, the best choice would be the one who has experience in the infrastructure management as well as data, process, and transaction modeling.

As a respondent, you are required to attend all the three sessions of the interview: (i) introduction (30-45 minutes), (ii) comprehension (30-45 minutes), and (iii) execution (180-240 minutes). *Introduction session*—in this session, the purpose of the survey and the proposed TFP Specification and TFP Tool is briefly introduced. *Comprehension session*—in this session, the content represented in all the forms of the proposed TFP Tool is carefully reviewed and understood so that experts have a clear understanding of the content. *Execution session*—in this session, respondents are required to answer all the questions contained in section 1 through 6 of the questionnaire. Questions are formulated based on four criteria: feasibility, usability, usefulness, and generalizability. As a respondent, you are required to review all the information attached to the questionnaire and respond to all questions presented in the questionnaire. The whole interview process is expected to be completed from within 4 to 5.5 hrs.

Use of Information and Procedure Adopt for Data Confidentiality

All the questions reflected in the questionnaire are optional. The result of the expert review will be compiled which is to be viewed and used by everyone associated with the approval of the proposed TFP Tool, and the design, implementation, and management of transactions in the domain of infrastructure management. The review data collected will be used to refine the forms developed for the proposed TFP Tool. Please do not provide information that is confidential or of a sensitive nature. The information provided will only be used to achieve objectives of this research only. Please inform us if you do not wish to publish your personal information or that of your organization.

Questions and Additional Information

A structured questionnaire is used to collect information from the experts during the interview; therefore, most of the questions will be dealt with during the interview. However, any question or additional information can be asked from the supervisor and investigator at the above-mentioned addresses.

Risks and its Remedial Measures

None of the risks; such as, breach of confidentiality, social stigmatization, threats to reputation, and psychological harm are anticipated for this research work. Therefore, it is requested not to provide any information that you deem is confidential or of a sensitive nature.

Respondent Rights

You are free to decline to participate and withdraw from the study at any time with no consequences. Please withhold any information that you do not wish to provide. If you have any concerns about your treatment of rights as a research respondent, you may call the Research Subject Information Line at (604) 822 8598, located in the UBC Office of Research Services at the University of British Columbia.

Potential Conflicts of Interest

As part of the protocol evaluation, this survey relates to the review of the proposed TFP Tool; therefore, no conflict of interest is anticipated between you or your organization and the researcher/investigator.

Questionnaire

The questionnaire is to be presented to the respondents during the interview. The questionnaire is divided into following six sections and three appendices: The first two sections collects general information about respondents. The section 3 and 4 represent questions related to the protocol feasibility and usability, whereas section 5 and 6 captures questions related to the protocol usefulness and generalizability.

Section—1: Respondent profile information

Section—2: Familiarity with infrastructure sectors and data, process and transaction modeling

Section—3: Transaction formalism protocol feasibility

Section—4: Transaction formalism protocol usability

Section—5: Transaction formalism protocol usefulness

Section—6: Transaction formalism protocol generalizability

Appendix—1: Transaction formalism protocol specification brief description

Appendix—2: Transaction formalism protocol tool detailed description—(empty forms)

Appendix—3: Transaction formalism protocol application—(filled forms)

Appendix—4: List of abbreviations used

The content attached to this questionnaire via Appendix—1, 2, 3, and 4 are re-arranged in the thesis to avoid duplication. In the thesis, the content attached at Appendix—1 and 2 is now presented in Chapter 6 and 7 respectively, and the content at Appendix—3 of the questionnaire is now attached at Appendix K. The content at Appendix 4 is now presented in the front section of this thesis.

QUESTIONNAIRE

Definitions of the words in the questionnaire with bold, italic, and underline are defined in the glossary of terms at the end of this document.

Section 1: Respondent Profile Information

This section captures general and technical profile information of the respondents.

Please fill out the following respondent profile information in Table 1-1.

S. No.	Information relating Respondent Profile	
A.	**Respondent General Profile**	
1	Respondent Name	
2	Respondent Position/Designation/Title	
3	Respondent Organization Name	
4	Respondent Tel No.	
5	Respondent E-mail Address	
B.	**Respondent Technical Profile**	
6	Years of Experience	
7	Field/Sector of Experience	

☐ Please check if you would like us to withhold your name and that of your organization from publication.

Date interview survey conducted: **/dd** **/MM** **/YYYY**

Section 2: Familiarity with Infrastructure Sectors and ***Data Modeling***, ***Process Modeling***, and ***Transaction Modeling***

2.1 What is your level of familiarity with the following infrastructure sectors? Please select one familiarity level for each infrastructure sector in Table 2-1.

Table 2-1 Familiarity with Infrastructure Sector

Infrastructure Sectors	Familiarity Level Unable to Rate 0	Not at all Familiar 1	Slightly Familiar 2	Somewhat Familiar 3	Moderately Familiar 4	Extremely Familiar 5
1. Transportation						
2. Water						
3. Wastewater						
4. Solidwaste Management						

2.2 What is your level of familiarity with data or information modeling, process modeling, and ***transaction modeling***? Please select one familiarity level for each expertise shown in Table 2-2.

Table 2-2 Familiarity with Data, Process, and Transaction Modeling

Expertise	Familiarity Level Unable to Rate 0	Not at all Familiar 1	Slightly Familiar 2	Somewhat Familiar 3	Moderately Familiar 4	Extremely Familiar 5
Data Modeling						
Process Modeling						
Transaction Modeling						

Section 3: Transaction Formalism Protocol Feasibility

3.1 Based on the review of the proposed eight-step TFP explained in Appendix 1, 2, and 3, please rate your level of agreement for the TFP feasibility on a scale of 1 to 5 for each question shown in Table 3-1. In case of disagreement, please record your concerns.

Feasibility—refers to the quality of the protocol that it is being usable, practical, and can be followed in terms of completeness, rightness, and reasonableness. The feasibility answers the question; Can the TFP be followed?

Table 3-1 Transaction Formalism Protocol Feasibility

Questions	Agreement Level					
	Unable to Rate	Strongle Disagree	Disagree	Neither Agree Nor Disagree	Agree	Strongly Agree
	0	1	2	3	4	5
Completeness: Does the TFP tool incorporate all the steps required for the design/improvement, implementation, and management of transactions?						
Rightness: Are the steps of the TFP tool right?						
Reasonableness: Are the steps of theTFP tool reasonable?						

Record your concerns, in case of disagreement:

Section 4: Transaction Formalism Protocol Usability

4.1 Based on the review of the proposed eight-step TFP explained in Appendix 1, 2, and 3, please rate your level of agreement for the TFP usability on a scale of 1 to 5 for each question shown in Table 4-1. In case of disagreement, please record your concerns.

Usability—refers to the quality of the TFP protocol that it is being workable in terms of learnability and ease of use. Usability answers the question; Is the TFP workable?

Table 4-1 Transaction Formalism Protocol Usability

Questions	Agreement Level					
	Unable to Rate	Strongle Disagree	Disagree	Neither Agree Nor Disagree	Agree	Strongly Agree
	0	1	2	3	4	5
Understandability: Is the TFP tool easy to understand?						
Applicability: Is the TFP tool easy to apply while defining transactions?						
Guidance/Supportability: Does the TFP tool provide sufficient guidance on how to fill various sections of the forms?						

Record your concerns, in case of disagreement:

Section 5: Transaction Formalism Protocol Usefulness

5-1 Based on the review of the proposed eight-step TFP explained in Appendix 1, 2, and 3, please rate your level of agreement for the TFP usefulness on a scale of 1 to 5 for each question shown in Table 5-1. In case of disagreement, please record your concerns.

Usefulness—refers to the quality of the TFP that it is being useful in terms of producing results that organizations find helpful in relation to effectiveness, efficiency, consistency, adaptability, and reusability. Usefulness answers the question; Is the protocol worth following?

Table 5-1 Transaction Formalism Protocol Usefulness

Questions	Agreement Level					
	Unable to Rate	Strongle Disagree	Disagree	Neither Agree Nor Disagree	Agree	Strongly Agree
	0	1	2	3	4	5
Effectiveness: Do you feel that the use of the TFP tool produce useful and effective results?						
Efficiency: Does the use of the TFP tool save you time and cost compared to defining transactions without using the proposed TFP tool?						
Consistency: Does the use of the TFP tool result in the creation of consistent transactions that are easily implementable in a variety of applications?						
Changeability/Adaptability: Does the use of the TFP tool result in the creation of transactions that are easily modifiable with changing requirements?						
Reuseability: Does the use of the TFP tool result in the creation/development of reuseable transactions?						

Record your concerns, in case of disagreement:

Section 6: Transaction Formalism Protocol Generalizability

6-1 Based on the review of the proposed eight-step TFP explained in Appendix 1, 2, and 3, please rate your level of agreement for the TFP generalizability on a scale of 1 to 5 for each question shown in Table 6-1. In case of disagreement, please record your concerns.

Generalizability—refers to the quality of the protocol that it is being applicable to a variety of communications within the AEC/FM and non-AEC/FM industries. The generalizability answers the question; Is the TFP applicable to define diverse communications in different fields?

Table 6-1 Transaction Formalism Protocol Generalizability

Questions	Agreement Level					
	Unable to Rate	Strongle Disagree	Disagree	Neither Agree Nor Disagree	Agree	Strongly Agree
	0	1	2	3	4	5
Generality: Is the proposed TFP applicable to formalize diverse communications in the AEC/FM and non-AEC/FM industries?						

Record your concerns, in case of disagreement:

Expert Review Survey Towards Transaction Formalism Protocol Validation

Glossary of Items

1. Data Modeling

Data modeling is the process of identifying entities, the relationship between those entities and their attributes. Data modeling is a method used to define and analyze data requirements needed to support the business processes of an organization.

1. Process Modeling

The process modeling relates to work process modeling that defines the way inputs are to be converted into useful outputs/results.

2. Transaction Modeling

The transaction modeling relates to communication process modeling that defines the way information is to be exchanged between the collaborative partners in a solo or atomic transaction/communication.