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INTEGRATED ASSET MANAGEMENT OF WATER AND WASTEWATER INFRASTRUCTURE SYSTEMS - BORROWING FROM INDUSTRY FOUNDATION CLASSES

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Abstract: Viewing water and wastewater infrastructure systems from a network or functional viewpoint down to an individual component goes hand in hand with life-cycle management. Therefore, three concepts are incorporated: (1) Strategic Planning; (2) Tactical Planning; and (3) Operational Planning. The data relevant to each of these areas are generated and managed by software applications that operate in isolation. A multi-level integration can link and share data among strategic, tactical, and operational asset management plans. The Industry Foundation Classes schema concept is used to develop a framework to support efficient sharing and management of data and planning information among strategic, tactical and operational asset management plans of the water and wastewater infrastructure systems. The proposed multi-level integration framework is comprised of a comprehensive database of water and wastewater infrastructure physical asset inventory, financial and consumer sectors that stores and manages flow of information through strategic, tactical, and operational asset management plans. Data are identified by reference of time and date (temporal) and by physical relation of data to the location of a facility in the water and wastewater infrastructure networks (spatial). The proposed framework enables the integration and interoperation of various domain-specific software applications through developing and maintaining a multi-level integration of strategic, tactical and operational asset management plans based upon the Industry Foundation Classes data model concept. Municipalities and water utilities can use the findings to make optimized asset management decisions.

1 INTRODUCTION

Grigg (2012) defines infrastructure asset management as “an information-based process used for life-cycle facility management across organizations”. This paper proposes a multi-level integrated asset management framework to store and manage flow of information through strategic, tactical, and operational asset management plans for water distribution and wastewater collection networks. The data relevant to each of these asset management planning models are generated and managed by software applications that operate in isolation. A multi-level integration should enable water infrastructure stakeholders and software developers to extract and exchange the required data and information from any of the strategic, tactical, and operational asset management planning model using a centralized neutral data file.

Environment Canada (2004) defines the water infrastructure system as comprised of “water treatment plants that purify our water, the water mains in the ground that transport water, and the towers and reservoirs that store water. The term includes the sewer pipes that carry away wastewater and the

sewage treatment plants that treat wastewater before returning it to the environment …". The other components of a water infrastructure system that include water and wastewater treatment plants, towers, and reservoirs are outside the scope of this study.

2 BACKGROUND

Froese (2003) indicated that information technologies (IT) play an effective role in architecture, engineering, construction, and facilities management (AEC/FM). Various domain-specific software applications are used to facilitate most of the AEC/FM design and management tasks, and the information entered into all of these computer tools describes the same physical project (Froese, 2003).

To facilitate efficient sharing and management of data between AEC/FM, the topic of interoperability has become one of the main areas for research and development in IT for the AEC/FM sectors (Froese, 2003). Froese, (2003) defines Interoperability as "the ability for information to flow from one computer application to the next throughout the lifecycle of a project which relies on the development and use of common information structures".

To develop an integrated AEC model structure, model-based systems have been known as the main empowering technology (Halfawy and Froese 2002). Caldas and Soibelman (2003) noted that model-based systems are being utilized more and more to support exchanging information among AEC/FM projects. Industry Foundation Classes (IFCs) are one of the most remarkable of these model-based systems. IFCs have had significant positive impact on integration and interoperability.

2.1 Industry Foundation Classes

The IFCs specification is developed by the International Alliance for Interoperability (IAI). The IFC specification is a neutral data format to describe, exchange, and share information among AEC/FM industry projects (Caldas and Soibelman, 2003). The latest version is IFC4 and is available at buildingSMART International Ltd.

The IFCs data model is substantially built in a hierarchical structure, and its object-oriented design enables complex relationships to exist between entities (Dimyadi et al., 2008). Entities can be physical objects such as watermain pipes, service connections, valves, etc. or conceptual entities such as processes, budgets, scheduling details, etc..

Froese (2003) noted that the scope of the IFCs is limited to the building industry and should be extended to a broader range of civil infrastructure to include the entire built environment. To some extend this has happened in the industrial sector with ISO 15926. This research presents a framework to support efficient sharing and management of data and planning information among strategic, tactical and operational asset management plans for the water and wastewater infrastructure systems, and to enable the integration and interoperation of various domain-specific software applications through developing and maintaining multi-level integrated asset management plans based upon the IFC data model concept. A critical functionality of a multi-level integration of strategic, tactical and operational asset management plans is the requirement to link and manage the inter-dependencies of these data, and to enable different applications to share these data through the use of the integrated asset management model.

Strategic planning is a long-term (10+ years) group of activities including capital planning, operational and maintenance planning, policy planning, risk management, and life-cycle costing at the management level of an organization. The organization policy levers and the level of service are established at this stage of planning. Embedded in and dependent on strategic planning, a tactical planning (2-10 years) cycle is required to prioritize capital works activities as well as operating and maintenance (O&M) activities, and to flag candidates for capital works and O&M activities. Operational planning is defined as plans that specify details on how overall objectives are to be achieved (Robbins and Coulter, 1996) and to implement tactical plans.

2.2 EXPRESS Modeling Language

EXPRESS (ISO 10303-11, 1994) is an internationally standardized general-purpose data modeling language in contrast to a domain-specific data modeling language. The data model structure is often represented using the EXPRESS-G notation-a graphical modelling language subset of EXPRESS language (ISO 10303-11, 1994) used for identifying model classes, data attributes and their relationships. Every object which is drawn in EXPRESS-G can be defined in EXPRESS. However, not every object which can be defined in EXPRESS can be drawn in EXPRESS-G (ISO 10303-11, 1994). This section presents the basic symbols used in the EXPRESS-G data modeling language.

2.2.1 Classes

Classes are identified in a rectangular box with solid lines and the name of class is enclosed in the box (ISO 10303-11, 1994). Figure 1 shows three examples of classes where Iwis means integrated water infrastructure system.

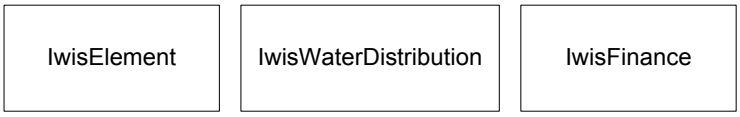

Figure 1: Classes (Entities)

2.2.2 Data Types

EXPRESS-G consists of four main data types as follows:

a) Simple data types

There are seven simple data types: BINARY, BOOLEAN, INTEGER, LOGICAL, NUMBER, REAL, and STRING which are shown in Figure 2. A simple data type is presented as a solid rectangular box with its name enclosed and a double vertical line at the right hand side of the box (Figure 2).

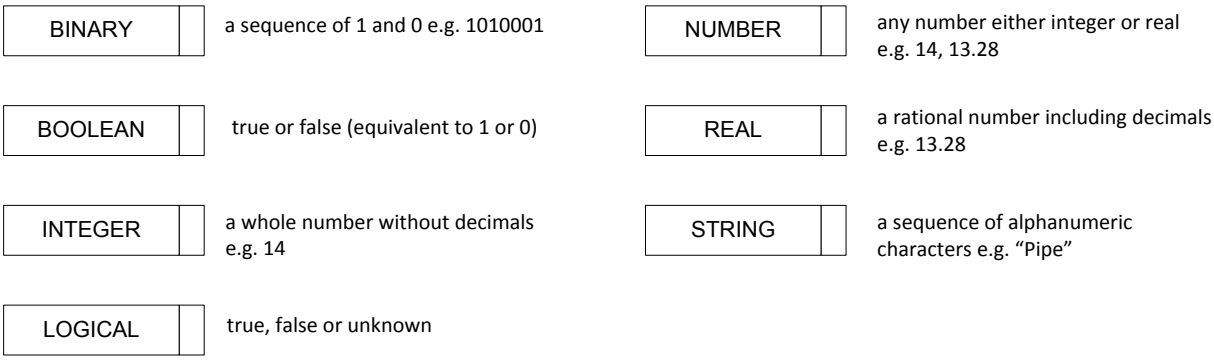

Figure 2: Simple data types in EXPRESS-G data modeling language

b) Enumeration data type

Data attributes can be described in an enumeration data type when there is a range of possible values and the attribute may only choose one value from the possible range. This data type is shown in a dashed lines rectangular box with a double vertical bar to the right. The name of enumeration data is enclosed into the box. Figure 3 shows an enumeration example for IwisPipeMaterial that enables the IwisPipeMaterial to choose only one type of pipe material.

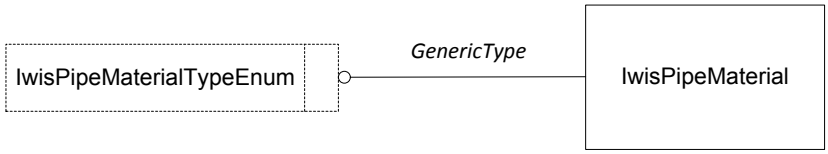

Figure 3: An example of enumeration data type in EXPRESS-G

c) Defined data type

A simple STRING data type can be used to define a data type but there are some types of data that require a detailed description. In this case a defined data type is used to make a clear description for a defined type of data. Figure 4 shows an example of a defined data type in EXPRESS-G. This type of data is shown in a dashed lines rectangular box with its name enclosed into the box.

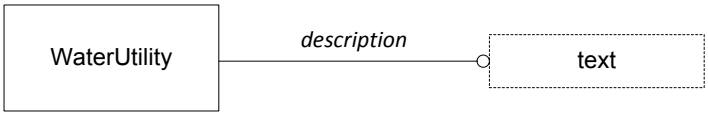

Figure 4: An example of defined data type in EXPRESS-G

d) Select data type

A select data type enables data attributes to choose the class based upon different purposes. For example, the IwisWaterDistributionElement enables selection of, watermain pipe, valve, hydrant or service connection (Figure 5). Select data type is shown in a rectangular box with dashed lines and a double vertical bar on the left hand side. The name of the data type is written in the box.

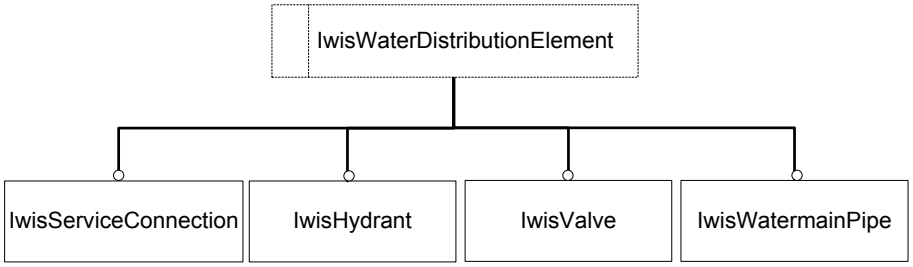

Figure 5: An example of select data type in EXPRESS-G

2.2.3 Relationships

Mandatory and optional relations are two types of attributes that are related to a class. The value of attributes must be given when a Mandatory relation is assigned to a class. However, it is not necessary for the optional attributes. Figure 6 shows an example of a mandatory and optional relation to IwisWaterDistributionElement where TotalLength has a mandatory relation and TotalVolume is considered an optional relation.

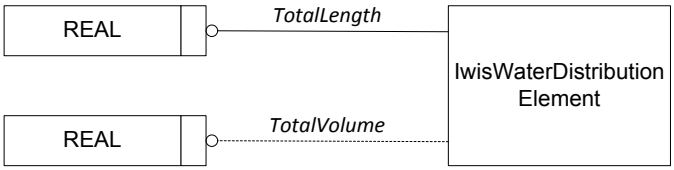

Figure 6: An example of a mandatory and optional relation in EXPRESS-G

The above discussion briefly introduced the EXPRESS-G data modeling language for the purpose of this study. A detailed discussion on this graphical data modeling language can be found in ISO 10303-11 (1994).

3 MULTI-LEVEL INTEGRATION FRAMEWORK

There are inter-dependencies and relationships that exist between strategic, tactical and operational (STO) asset management plans for water and wastewater infrastructure systems. The data relevant to each of these areas typically generated and managed by separate software applications that operate in isolation. Multi-level integration of STO planning is intended to link and manage the inter-dependencies of these plans. The IFCs schema concept is used to develop a centralized database management system that enables the interoperation of various function-specific tools and the exchange of data among different asset management planning disciplines.

The proposed multi-level integration framework is comprised of a comprehensive database of water and wastewater infrastructure physical infrastructure assets with financial and consumer sectors that exchanges and stores data through strategic, tactical, and operational planning (Figure 7). An Integrated Water Infrastructure System (IWIS) database stores and manages flow of information between strategic, tactical, and operational planning models. Data will be identified by reference to time and/date (temporal) and by physically relation of data to the location of a facility in the water infrastructure network (spatial).

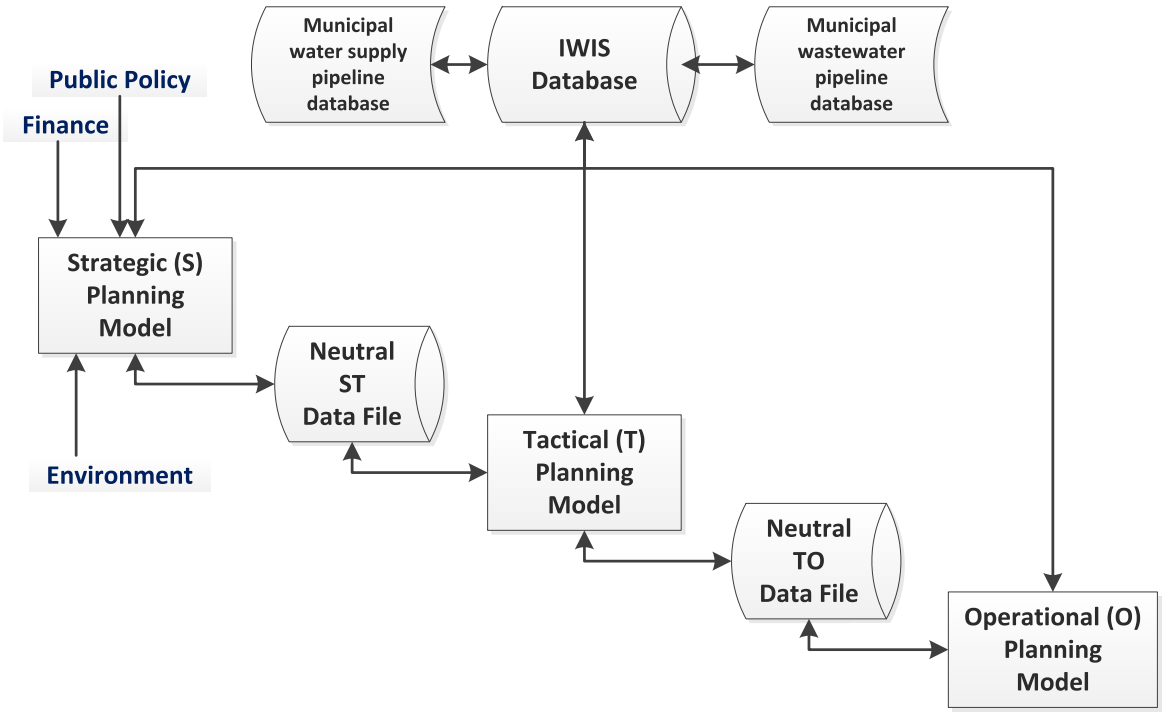

Figure 7: The Research vision for Multi-Level Integration

3.1 Asset Management Plans

This section presents the typical steps required to develop strategic, tactical and operational asset management plans for water infrastructure systems.

3.1.1 Strategic Planning

The implementation steps for strategic planning of a water infrastructure system are categorized as follows (adopted from Uddin et al., 2013):

1. establish policy levers
2. establish level of service performance (consumer satisfaction) policies
3. categorize urban water infrastructure networks needs and funding sources
4. estimate long-term (10+ years) financial performance
5. prepare long-term (10+ years) capital works program
6. prepare long-term operating and maintenance program

Types of modeling techniques used for this level of planning currently include financial spreadsheets, simple data base management systems (DBMS), system dynamics models, large business oriented models, scenario based models, etc.

3.1.2 Tactical Planning

The implementation steps for tactical planning of a water infrastructure system are summarized as follows (adopted from Uddin et al., 2013):

1. prioritize all capital works activities,
2. prioritize all operating and maintenance (O&M) activities,
3. flag specific activities for capital works, and
4. flag specific activities for O&M activities

Types of modeling techniques used for this level of planning currently include deterministic mathematical modeling, simulation, optimization, etc..

3.1.3 Operational Planning

The implementation steps for operational planning of a water infrastructure system are categorized in the three disciplines of (1) engineering and design, (2) construction, and (3) operation and maintenance within a water utility (adopted from Uddin et al., 2013):

1. Engineering & Design
   1.1. perform structural and hydraulic analysis
   1.2. analyze cost effectiveness of project level alternatives
   1.3. prepare plans and specifications and perform actions
   1.4. analyze cost effectiveness of O&M activities
   1.5. analyze cost effectiveness of capital works

2. Construction
   2.1. perform capital works

3. Operation & Maintenance
   3.1. perform structural and hydraulic analysis
   3.2. perform O&M activities
   3.3. collect condition assessment and financial data

Types of modeling techniques used for this level of planning currently include simulation models, “what-if” scenario models, sensitivity analysis, modeling infeasibilities, opportunity costs and marginal economic value, etc..

The implementation steps of the above asset management plans need to be considered when developing the neutral strategic-tactical (ST) and tactical-operational (TO) data files to recognize data and planning information to be exchanged between the strategic, tactical and operational planning models.

3.2 Neutral Data Files

The neutral strategic-tactical and tactical-operational data files are divided into the three subtypes of neutral physical infrastructure asset, finance and consumer data files (Figure 8). A brief description of each subtype is presented in this section. The division into these three sectors is established in the literature and is used in systems dynamics models developed for strategic planning (Rehan et al., 2011, Rehan et al., 2013 and Rehan et al., 2014).

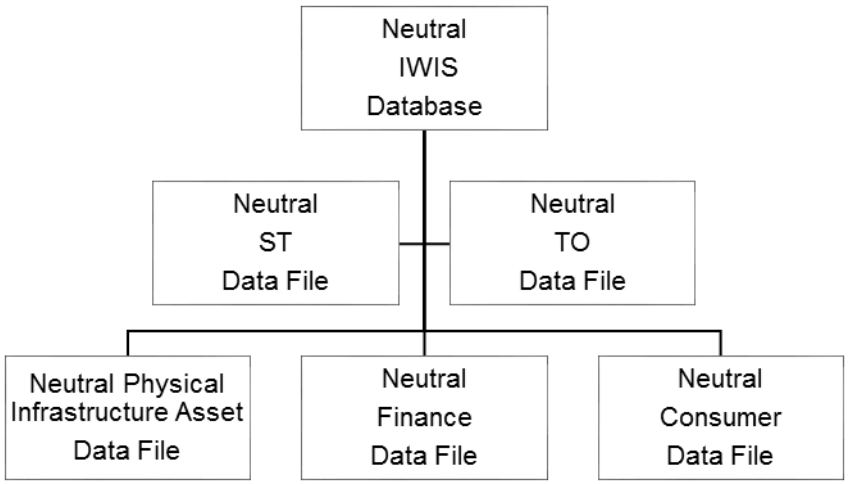

Figure 8: A hierarchy of the neutral data files

3.2.1 Physical Infrastructure Asset Sector

This sector represents the asset inventory of water distribution and wastewater collection networks. The physical condition of the water network is classified based upon the age distribution of water pipes (e.g. in 25-year increment). The physical condition of the wastewater network is divided into five variables based upon the internal condition of the pipes using the UK's Water Research Centre rating system proposed in the fourth edition of the Sewerage Rehabilitation Manual.

3.2.2 Finance Sector

This sector describes the network's financial condition including revenues, expenses, fund balance, debt, utility user fee, etc.. Revenue is the utility's income that is calculated based upon user fee, total water consumption, and total generated sewage. Fund balance is the difference between the revenue and expenditures of the network in dollars value, and user fee is the unit cost of water and sewage ($\$/m^3$) that a utility charges its consumers to cover the expenses associated with the water and sewage services.

3.2.3 Consumer Sector

This sector presents the behavior of consumers in response to user fee oscillations (i.e. water demand) and level of service delivered to them. This sector establishes the policy levers and level of service performance (consumer satisfactions) policies.

The neutral strategic-tactical (ST) and tactical-operational (TO) data files will be developed to support efficient sharing and management of data and planning information among strategic-tactical and tactical-

operational models using EXPRESS-G data modeling language. Figure 9 shows a high-level example of the integrated water infrastructure system model structure displaying in EXPRESS-G.

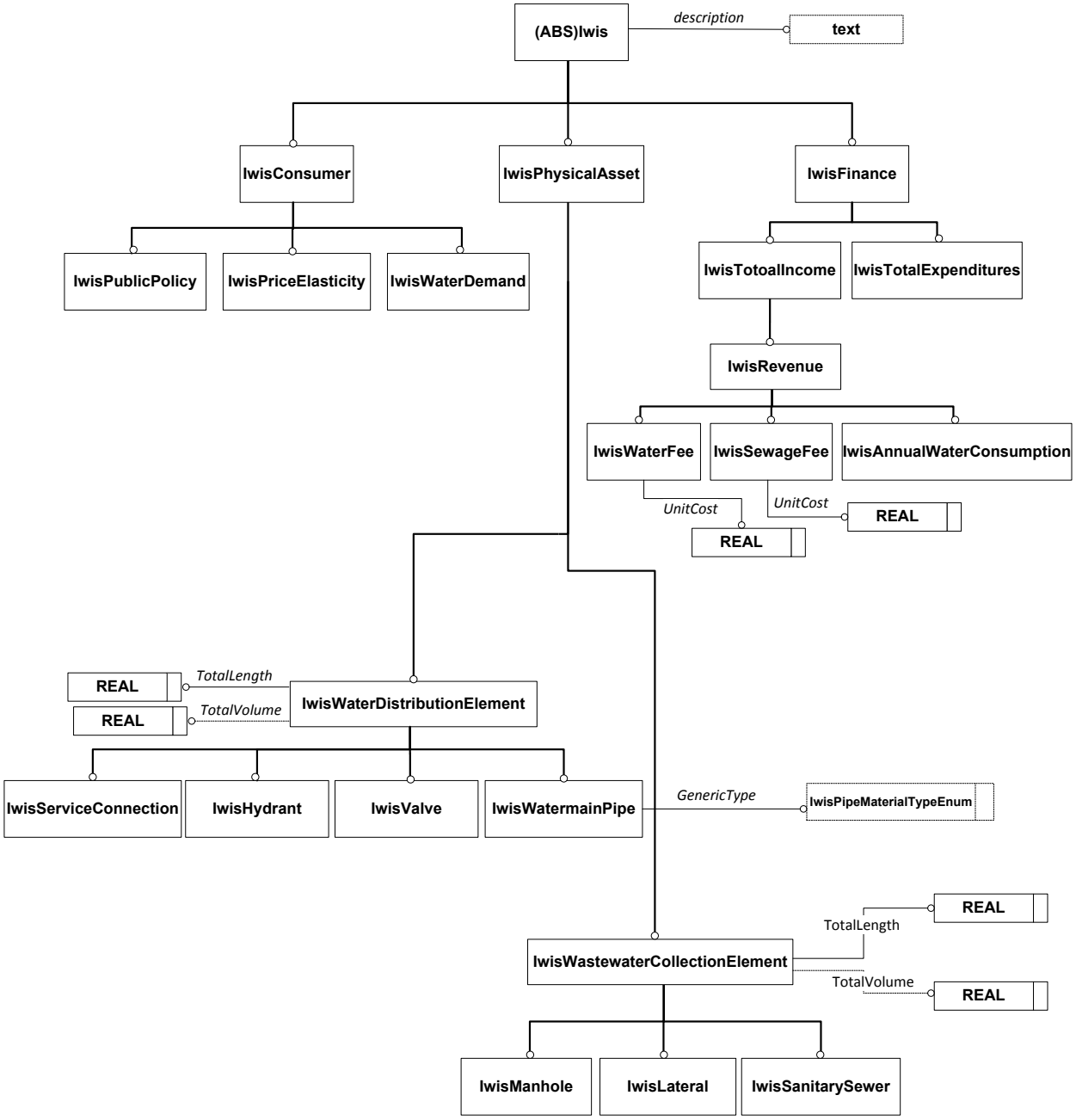

Figure 9: A High-level example of the integrated water infrastructure system (Iwis) model structure in EXPRESS-G

4 CONCLUSIONS

This paper reviews the basic concepts of Industry Foundation Classes and the EXPRESS-G data modeling language. A framework is proposed to integrate strategic, tactical and operational asset management planning models for the water and wastewater infrastructure systems. Further work is needed to completely develop the proposed multi-level integration framework. It is important that the developed neutral IWIS data files are reviewed by the water infrastructure industry experts and software developers to ensure that the specification is validated universally by the agreement of a wide cross section of water infrastructure industry experts and does not rely on a particular region. It should also be demonstrated with various currently utilized software packages. The proposed framework is the first known approach for data integration, sharing, and exchange between strategic, tactical, and operational asset management planning models of the water and wastewater infrastructure systems. In practice, this framework should enable water infrastructure stakeholders and software developers to extract and exchange the required data and information from any of the strategic, tactical, and operational planning model using a centralized IWIS neutral data file.

Acknowledgements

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