Planning Street Transit Stops Under Uncertainties: A Fuzzy Logic Approach

by

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Abstract

This research concerns with the effect of street transit stop-related factors on transit demand attraction. Key stop-related factors that influence passengers’ perception of the service were identified along with their recommended standards. It was shown that current transit planning manuals and guidelines suffer from the following limitations: (a) they are silent regarding the relative importance of stop-related factors; (b) they exhibit great deal of variability in service planning standards; and (c) they fail to provide specific standards for different city sizes.

The number of factors and variability in service planning standards involved in transit stop planning make it almost impossible for transit planners to decide on the location, interspacing, and design of street transit stops based merely on intuition and experience. Further, classical decision-making approaches, while useful, do not adequately consider the site-specific conditions and uncertainties associated with service standards.

To address the above issues, this research adopted a twofold approach. First, an expert opinion survey was conducted among a panel of transit experts across Canada to (a) understand the relative importance of various transit stop-related factors with respect to their attractiveness to passengers; and (b) collect best-practices used in the transit industry to select typical standards for those factors. Second, an index-based decision-support tool was developed through the solicitation and synthesis of experts’ opinions using Analytical Hierarchical Process and Fuzzy Synthetic Evaluation. The developed index-based tool provides a simple way to quantitatively evaluate transit stops, based on a single score (or rating index), considering various factors that affect transit ridership. The developed tool is intended to help transit planners make informed decisions regarding the location, interspacing, and design of existing/new street transit stops.

The results showed that, among all spatial (i.e. stop location and interspacing) factors, land use is the most important factor that influences demand attraction, while the most important design factor is real-time information provision. Furthermore, the dataset showed that a lower passenger demand is required in small cities to provide a particular amenity (e.g. seat, shelter, or CCTV camera) at the stop compared to the demand required in large cities to provide the same amenity.
Preface

This research has been conducted and composed in the form of a thesis and papers by the author, Hassaan Masood, under supervision of Dr. Ahmed Idris.

The author was responsible for reviewing the literature, designing the survey, collecting and analyzing data, developing the index-based tool, and testing different case studies. The expert opinion survey was approved by the UBC’s Behavioral Research Ethics Board (UBC BREB Number: H16-02271). The research supervisor provided valuable guidance and feedback towards the completion of this thesis and the preparation of presentations and publications.

The following publications are peripheral to the work described in the following chapters of this thesis:

**Chapter 2, Chapter 3, and Chapter 5:**


**Chapter 2, Chapter 3, and Chapter 6**
Table of Contents

Abstract ................................................................................................................................. iii
Preface ................................................................................................................................. iv
Table of Contents ............................................................................................................... v
List of Tables ...................................................................................................................... ix
List of Figures .................................................................................................................... x
List of Abbreviations ........................................................................................................ xii
Acknowledgements .......................................................................................................... xiii
Dedication ........................................................................................................................... xiv

Chapter 1: Introduction ..................................................................................................... 1
  1.1 Outline .............................................................................................................................. 1
  1.2 Background and Motivation ........................................................................................... 1
  1.3 Research Motivation ...................................................................................................... 3
  1.4 Research Goal and Objectives ...................................................................................... 4
  1.5 Research Methodology ................................................................................................. 5
  1.6 Research Outline .......................................................................................................... 7

Chapter 2: Literature Review .......................................................................................... 9
  2.1 Outline .............................................................................................................................. 9
  2.2 Decline in Ridership ........................................................................................................ 9
  2.3 Transit Stop Planning .................................................................................................... 12
    2.3.1 Limitations of Mathematical and Simulation Models ............................................... 13
    2.3.2 Limitations of Transit Agency Manuals .................................................................. 16
    2.3.3 Uncertainty Analysis ............................................................................................... 18
  2.4 Expert Opinion Survey ................................................................................................ 21
    2.4.1 Survey Design .......................................................................................................... 23
    2.4.2 Survey Validation Test ............................................................................................. 25
    2.4.3 Survey Reliability Test ............................................................................................. 30
  2.5 Fuzzy Set Theory .......................................................................................................... 31
### Chapter 3: Research Methodology

3.1 Outline ........................................................................................................... 58
3.2 Research Framework ...................................................................................... 58
   3.2.1 Phase – 1: Hierarchical Framework Development .................................... 58
   3.2.2 Phase – 2: Expert Opinion Survey ............................................................. 60
   3.2.3 Phase – 3: TRANSDEX ........................................................................ 61
3.3 Summary ........................................................................................................ 63

### Chapter 4: Hierarchical Framework Development

4.1 Outline ........................................................................................................... 64
4.2 Factors vs. Indicators ..................................................................................... 64
4.3 Hierarchical Chart for Transit Stop Evaluation ............................................... 68
   4.3.1 Spatial and Demographical Factors ......................................................... 68
   4.3.2 Design Factors ...................................................................................... 70
4.4 Uncertainties in Transit Stop Planning ............................................................. 73
   4.4.1 Parametric Uncertainties ..................................................................... 73
   4.4.2 Model Uncertainties ............................................................................. 74
   4.4.3 Scenario Uncertainties ........................................................................ 75
4.5 Summary ........................................................................................................ 76
6.5.1 Case Study – 1: Analyzing Existing Transit Stops Using VETOP and PETOP ............... 132
6.5.2 Case Study – 2: Allocating New Transit Stop Using NETOP ................................ 146
6.6 Summary .................................................................................................................. 152

Chapter 7: Conclusions, Contributions, and Future Recommendations .......................153

References ......................................................................................................................157

Appendix: Expert Opinion Survey ..................................................................................180
List of Tables

Table 1-1: Population Trends in Canada ................................................................. 1
Table 2-1: Population Coverage (percentage) ......................................................... 15
Table 2-2: Stats about Past Literature Consulted to Detect Sample Size ................. 24
Table 2-3: Proportion of Experts Required to Establish Content Validity ............... 27
Table 2-4: Sources of Alpha Coefficient .................................................................. 31
Table 2-5: TFN for a Random Indicator .................................................................. 38
Table 2-6: Saaty’s Scale of Relative Importance ..................................................... 46
Table 2-7: RCI for computation of Consistency Index ............................................. 48
Table 2-8: Fuzzy Fundamental Scale .................................................................... 54
Table 5-1: Statistics about 5 Categories of Canadian Cities (Statistics Canada, 2011) 78
Table 5-2: Survey Statistics (Response Rate) ......................................................... 93
Table 5-3: Explanatory Example for Construct Validity ......................................... 93
Table 5-4: Weighting Criteria for Years of Experience of Expert ......................... 94
Table 5-5: Hypothesis Testing Results for Construct Validity ............................... 95
Table 5-6: Conversion of Qualitative Scale to Quantitative Scale ......................... 95
Table 5-7: Explanatory Example for Cronbach’s Alpha Reliability Test ................ 96
Table 5-8: Cronbach’s Alpha Results for Explanatory Example ........................... 96
Table 5-9: Explanatory Example for Result Analysis of Part A .............................. 98
Table 5-10: Explanatory Example for Result Analysis of Part B ............................ 100
Table 5-11: Hypothesis Testing Results for Part B ............................................... 100
Table 5-12: Survey Statistics (Years of Experience) .............................................. 102
Table 5-13: Priority Ranking for Transit Stop Planning Factors ............................ 107
Table 5-14: Best-practices for Transit Stop Planning Indicators ......................... 108
Table 6-1: Variation of Membership Values with Change in Degree of Fuzziness 117
Table 6-2: Benchmarking Membership Functions of Indicator ............................. 119
Table 6-3: Indicator Values for Stop Evaluation Having Basic Infrastructure ........ 134
Table 6-4: Indicator Values for Stop Evaluation Having Advanced Infrastructure .... 142
Table 6-5: Indicator Values for Stop Allocation using NETOP ............................. 151
List of Figures

Figure 1-1: Research Methodology ................................................................. 6
Figure 2-1: Trends in Auto Sale, Ridership, and Transit fare.......................... 11
Figure 2-2: Fuzzy Operations ........................................................................ 36
Figure 2-3: Features of a Membership Function ............................................ 36
Figure 2-4: Calculating Membership, Cardinality, and Normalized Fuzzy Sets of Fuzzy Input .... 38
Figure 2-5: Calculating Membership, Cardinality, and Normalized Fuzzy Sets of Crisp Input .......... 41
Figure 2-6: Hierarchical Level for Aggregation ............................................. 41
Figure 3-1: Research Framework .................................................................. 59
Figure 3-2: Location of Large and Small Cities in Canada ______________________ 60
Figure 3-3: Tri-Level Street Transit Stop Index Framework ............................. 62
Figure 4-1: Categories of Factors Effecting Ridership ................................... 66
Figure 4-2: Hierarchical Chart of Attributes and Indicators for Transit Stop Planning ........... 72
Figure 4-3: Relevance of Categories of This Study with Rowe and Mahmassani ............. 74
Figure 5-1: Survey Instrument Design ............................................................ 80
Figure 5-2: Screenshot for Section A of Survey (Prioritization) ......................... 82
Figure 5-3: Explanatory Example for Section B of Survey (Best-practices) ............. 84
Figure 5-4: Screenshot for Section B of Survey (Collecting Tri-category Best-practices) ......... 86
Figure 5-5: Screenshot for Section B of Survey (Collecting Binary Best-practices) ............ 87
Figure 5-6: Screenshot for Section B of Survey (Skipping Question) .................... 89
Figure 5-7: Screenshot for Survey Feedback .................................................... 90
Figure 5-8: Geographic Distribution of Experts .............................................. 102
Figure 5-9: Survey Feedback Statistics ........................................................... 103
Figure 6-1: Home Page of TRANSDEX .......................................................... 112
Figure 6-2: TRANSDEX Interface for Framework Development ...................... 115
Figure 6-3: Memberships for Varying Degree of Fuzziness ............................ 119
Figure 6-4: Membership Functions of Indicator According to Values of Table 6-2 .......... 120
Figure 6-5: TRANSDEX Interface for Benchmarking and Fuzzy Calculations .......... 123
Figure 6-6: Relative Weights of Factors ........................................................ 125
Figure 6-7: Root Mean Square Error .............................................................. 126
Figure 6-8: Weighted Root Mean Square Error ................................................................. 126
Figure 6-9: Weighted Pairwise Comparison Error ............................................................ 127
Figure 6-10: TRANSDEX Interface for Prioritization ....................................................... 128
Figure 6-11: Possible Combinations for Prioritization ..................................................... 128
Figure 6-12: TRANSDEX Interface for Result Generation ............................................... 131
Figure 6-13: Transit Stop Selected for Evaluation with Basic Infrastructure .................... 133
Figure 6-14: Stop Circle for Calculating Walking Distance (Stop Catchment Area) .......... 135
Figure 6-15: TRANSDEX Results for Case Study – 1(a) ............................................... 139
Figure 6-16: Transit Stop Selected for Evaluation with Advanced Infrastructure .......... 141
Figure 6-17: TRANSDEX Results for Case Study – 1(b) .................................................. 145
Figure 6-18: Location of Street for Transit Stop Allocation .............................................. 147
Figure 6-19: Framework for NETOP .............................................................................. 150
## List of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>AHP</td>
<td>Analytical Hierarchical Process</td>
</tr>
<tr>
<td>APTA</td>
<td>American Public Transportation Association</td>
</tr>
<tr>
<td>ASCE</td>
<td>American Society of Civil Engineers</td>
</tr>
<tr>
<td>BC</td>
<td>British Columbia</td>
</tr>
<tr>
<td>CAD / USD</td>
<td>Canadian Dollar / U.S. Dollar</td>
</tr>
<tr>
<td>CBD</td>
<td>Central Business District</td>
</tr>
<tr>
<td>CR</td>
<td>Consistency Ratio</td>
</tr>
<tr>
<td>CUTA</td>
<td>Canadian Urban Transit Association</td>
</tr>
<tr>
<td>CVI</td>
<td>Content Validity Index</td>
</tr>
<tr>
<td>FSE</td>
<td>Fuzzy Synthetic Evaluation</td>
</tr>
<tr>
<td>MCDM</td>
<td>Multi-Criteria Decision-Making</td>
</tr>
<tr>
<td>NACTO</td>
<td>National Association of City Transportation Officials</td>
</tr>
<tr>
<td>NETOP</td>
<td>allocating NEw transit sTOP</td>
</tr>
<tr>
<td>OCTA</td>
<td>Orange County Transportation Authority</td>
</tr>
<tr>
<td>PETOP</td>
<td>imProving Existing transit sTOP</td>
</tr>
<tr>
<td>PTSG</td>
<td>Palm Tran Service Guideline</td>
</tr>
<tr>
<td>RR</td>
<td>Response Rate</td>
</tr>
<tr>
<td>SAW</td>
<td>Simple Additive Weight</td>
</tr>
<tr>
<td>SEPTA</td>
<td>SouthEastern Pennsylvania Transportation Authority</td>
</tr>
<tr>
<td>TCRP</td>
<td>Transit Cooperative Research Program</td>
</tr>
<tr>
<td>TFN</td>
<td>Triangular Fuzzy Number</td>
</tr>
<tr>
<td>TRANSDEX</td>
<td>TRANsit Stop inDEX</td>
</tr>
<tr>
<td>USDOT</td>
<td>United States Department of Transportation</td>
</tr>
<tr>
<td>VETOP</td>
<td>eValuating Existing transit sTOP</td>
</tr>
</tbody>
</table>
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DEDICATED TO MY BELOVED PARENTS,
FROM WHOM I HAVE DERIVED PRAYERS,
KNOWLEDGE, LOVE, AND
ENCOURAGEMENT
Tribute to the late Prof. Lotfi A. Zadeh

Feb 4th, 1921 – Sep 6th, 2017

For founding and developing

The Fuzzy Set Theory
Chapter 1: Introduction

1.1 Outline

This chapter starts with a discussion of the problem background and research motivation in Section 1.2, followed by research motivation in Section 1.3, research goal and objectives in Section 1.4, and research methodology in Section 1.5. Finally, Section 1.6 demonstrates the structure of the thesis.

1.2 Background and Motivation

The world population is increasing in a tremendous fashion (Lutz and KC 2010) which affects the economic, social, and environmental sustainability of urban communities (Lutz et al. 2001). Particularly in Canada, the population has increased from 13.7 million in 1950 to 36 million in 2015, and is expected to increase to 50 million by 2100 (Nations 2015). Based on population, the Canadian Urban Transit Association (CUTA 2014) has classified Canadian cities into five categories. Table 1-1 shows the increase in population from 2006 to 2011 in these five categories.

Table 1-1: Population Trends in Canada
(Statistics Canada, 2011)

<table>
<thead>
<tr>
<th>Id</th>
<th>Category</th>
<th>Population Range</th>
<th>2006</th>
<th>2011</th>
<th>Difference ∆</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Major metropolitan area</td>
<td>≥ 2 million</td>
<td>2,503,281</td>
<td>2,615,060</td>
<td>111,779</td>
<td>4.50</td>
</tr>
<tr>
<td>2</td>
<td>Large cities</td>
<td>400,000 – 2 million</td>
<td>8,225,289</td>
<td>8,852,792</td>
<td>627,503</td>
<td>7.62</td>
</tr>
<tr>
<td>3</td>
<td>Medium cities</td>
<td>150,000 – 400,000</td>
<td>3,675,074</td>
<td>3,960,754</td>
<td>285,680</td>
<td>7.78</td>
</tr>
<tr>
<td>4</td>
<td>Small cities</td>
<td>50,000 – 150,000</td>
<td>5,554,039</td>
<td>5,899,965</td>
<td>345,926</td>
<td>6.22</td>
</tr>
<tr>
<td>5</td>
<td>Small and rural communities</td>
<td>≤ 50,000</td>
<td>12,148,117</td>
<td>11,655,214</td>
<td>492,903</td>
<td>4.22</td>
</tr>
</tbody>
</table>

To meet the mobility needs of this growing population, in Canada, auto sales has increased from 1.6 million in 2011 to 2 million in 2015 (Satistics Canada 2016). Such increase in auto sales has increased traffic congestion to an extent that the annual congestion cost in Toronto has now reached CAD $6 billion. In Montreal, the total annual cost of congestion is CAD $1.4 billion.
which has increased by 50% between 1998 and 2003 (Urban Transportation Task Force 2012). Traffic congestion has a significant role in increasing the level of pollutants in the air because of more stop-go-stop mechanism of traffic (Barth and Boriboonsomsin 2008). Up to 16,000 people die each year due to car pollution which is estimated at 4 tons of pollutants annually in North America. The problem of asthma in children has increased by 23% from 1980 to 1990 (City of Windsor 2016). Most of these problems can be addressed by switching to sustainable modes of transportation such as public transit, bike, and walk. Traffic congestion can be solved by switching to transit given that a single bus can replace 50 single occupancy vehicles (City of Windsor 2017). In addition, transit can also preserve the natural non-renewable resources knowing that a single bus can save 70,000 liters of fuel a year (City of Windsor 2017). Further, public transit can reduce carbon dioxide emissions by 37 million metric tons annually (APTA 2008).

In spite of offering numerous advantages, public transit is now suffering from low ridership. This decline in ridership is due to two main reasons: lack of governmental support towards transit-oriented development, and uncontrolled auto sale. From 1950 to 1960, the support of Canadian government towards transit resulted in an increase in ridership which was on par with European countries (Soberman 1983). This increasing trend reached its peak in the 1990s, but afterwards it started to decline gradually. In 1991, the tax on buying new cars was reduced by 5.5%. Other economic factors like increased buying capacity also contributed towards more auto purchase. This all led to an increase in auto use and a decrease in transit ridership. This decrease in ridership ultimately resulted in a decrease in transit revenue which led to a greater deficit. To cover this deficit gap, transit fare was increased. But this increase in transit fare resulted in further decrease in ridership (Perl, A. and Pucher 1995). After 1990, transit ridership also decreased because the demographic distribution up till 1990s was in favor of transit, but after 1990s, transit failed to facilitate the demographic distribution related to age, household, and employment (CUTA 1991). The established land development guidelines were focusing on metropolitan growth, urban decentralization, and suburban development. In Toronto, where transit stops were located near office areas, 25% of staff utilized public transit. However, new offices were developed where near-by vast undeveloped areas have no transit stop (Perl, A. and
Pucher 1995). This focus on urban land development and completely ignoring urban transportation infrastructure eventually led to decline in ridership (Sancton 2000).

Increase in transit fare or transit users are the only means to increase revenue and decrease transit deficit. While ridership is further decreased by 1% with every 3% increase in transit fare (Litman 2004), a more sustainable way of improving ridership is to place transit stops near commercial areas where jobs are located (Cervero and Guerra 2011). Transit stops control the spatial and demographic factors of an area and improve the riders’ perception towards transit. Spatial factors include accessibility to stops, land use planning, and spacing between transit stops; while demographic factors include the socio-economic characteristics within stop catchment area. Normally, it is believed that waiting time is perceived to be twice as it actually is (Taylor et al. 2009). However, transit stop design factors (e.g. real-time information provision) can improve passengers’ perception towards transit and give a perception of shorter waiting and transfer time. Besides passenger perception, transit stop also affect the transit emissions and conflicts with traffic (Koshy and Arasan 2005). Therefore, in this research, different factors associated with transit stops are studied as mean of improving ridership.

1.3 Research Motivation

Due to the continuous downfall of ridership in the past few decades, transit agencies and the scientific community have put much efforts in developing transit stop guidelines and best-practices (Fitzpatrick et al. 1996; TCRP 1998, 2007; U.S. Department of Transportaion Washington D.C 2014). Similarly, many researchers have studied the effect of different stop level factors (Alonso et al. 2011; Feder 1973; Fernandez 2007; Fernández 1999; Foda and Osman 2010; Gao et al. 2009; Li and Bertini 2008; Minnpost 2016; Saka 2001; Wang and Ye 2015; Xin et al. 2015). While useful, these studies and agency manuals do not provide best-practices for all transit stop-related factors. Best-practices for many factors are ill-defined which create ambiguity in stop planning process. The best-practices provided by agency manuals or literature are not categorized as a function of city size and are recommended as generalized guidelines. These generalized guidelines make it difficult for the transit planners to decide on transit stop location or amenities provision. Furthermore, all studies considered these factors to be independent of each other, but superimposing these factors make the planning process more
complex. The relative importance of these factors is not provided in past literature which makes the stop planning process subjective, intuitive, and qualitative instead of quantitative. Previous studies have shown that the waiting time is perceived as twice of the actual time but agency manuals and past literature do not suggest amenities for passenger comfort in a priority order which can reduce this perception.

Up till now, deterministic approaches have been used to develop models to study the effect of transit stop factors. These models have focused only on some factors while neglecting other factors and the uncertainties associated with those factors. The human decision-making capabilities are vague and ambiguous which result in different types of uncertainties in the subjective, intuitive, and qualitative nature of transit stop planning process. In addition, there is no tool available which can analyze all the transit stop factors quantitatively in an inter-dependent manner while considering the effect of uncertainties. As such, it is very difficult for a transit planner to evaluate an existing stop, locate new stops, or decide on the amenities which are to be provided at the stop for passenger comfort. Therefore, more research is required to develop best-practices and priority order for stop-related factors. There is also a need for a tool which can be helpful for the transit planners in making informed decisions regarding transit stop planning.

1.4 Research Goal and Objectives
This research aims to improve transit ridership by focusing on transit stop-related factors which include spatial, socio-demographic, and design factors. This aim is achieved by quantitatively evaluating existing transit stops, improving existing transit stops by providing necessary amenities for passenger comfort, and allocating new transit stops. Quantitative judgement includes selecting factors related to transit stop planning, developing best-practices for those factors, and developing a decision-making tool for street transit stop planning using an index-based approach. Following are the main objectives of this research.
1. Identify key street transit stop-related factors which affect transit ridership – by reviewing past literature and transit agency manuals.

2. Develop best-practice guidelines and order of prioritization for small and large cities – by reviewing past literature, transit agency manuals, and conducting transit expert opinion survey.

3. Develop a customized decision-support tool for quantitative assessment of street transit stops, which incorporate developed best-practice guidelines and prioritization – by applying fuzzy synthetic evaluation technique.

1.5 Research Methodology

To cover literature gaps, this research was conducted in three phases and two-fold approach was adopted, as shown in Figure 1-1. At first phase, literature was consulted to identify those stop-related factors which affect ridership. A comprehensive list of factors was collected and shared with the transit experts for their feedback. Analyzing the expert’s feedback, a hierarchical network of factors was developed and detailed best-practices and prioritization of these factors were gathered from past literature which showed some limitations. These limitations were categorized into two main classes. First, past literature lacks the best-practices and priority order for most of the stop-related factors identified in hierarchical framework. Those factors for which best-practices are provided, they vary a lot, do not capture the degree of variation, and provide generalized best-practices instead of city wise best-practices. Second, literature shows transit stop planning process to have a subjective nature which largely depends on the transit planners experience aided with some service standards. This subjective nature of the planning process having many factors and indicators involved inculcate uncertainties making it difficult for the transit planner to make informed decisions. Further, none of the previous work, either mathematical or simulation work, has considered the effect of uncertainties on combined and super-imposed relationship between different transit stop planning factors. In spite of dealing with uncertainties in both long-run and short-run decisions in transit stop planning, there is no systematic framework available which can identify, categorize, and analyze uncertainties in major transit stop planning decisions.
1. Review literature to identify stop-related factors which effect ridership
2. Consult transit experts to develop hierarchical chart for stop-related factors
3. Review literature to collect detailed best-practices and priority order of hierarchical chart
4. Categorize literature limitations into two classes
   4.1 Lack of best-practices for most factors
   4.2 Lack of priority order for most factors
   4.3 Huge variations in best-practices
   4.4 Generalization of best-practices
4.1 Subjective nature of transit stop planning
   4.2 Lack of considering uncertainties
   4.3 Lack of considering super-imposed effect
   4.4 Lack of quantitative assessment of stops

Phase - 2

1. Conduct an expert opinion survey among transit experts working across Canada
2. Use CUTA membership directory as the sample frame
3. Preserve all data on secure UBC server
4. Apply validity and reliability test on survey responses
5. Apply statistical testing to develop best-practices of factors
6. Apply analytical hierarchical process to develop priority order of factors
7. Calculate degree of fuzziness to capture variation in expert opinions
8. Apply statistical testing to test hypothesis that best-practices of small cities are equal to large cities

Phase - 3

1. Classify uncertainties into parameter uncertainties, model uncertainties, and scenario uncertainties
2. Develop a tri-level tri-modular decision-support tool, TRANSDEX
3. Develop VETOP to evaluate the existing transit stop
4. Develop PETOP to improve the existing transit stop
5. Develop NETOP and its algorithm to allocate new transit stops
6. Apply TRANSDEX to basic and advanced transit stops using VETOP and PETOP
7. Apply TRANSDEX to allocate new transit stop along a street using NETOP

Figure 1-1: Research Methodology
To cover the first limitation of literature, in second phase of research, an expert opinion survey was conducted among transit experts working across Canada. For this survey, CUTA membership directory was used as a sample frame with a sample population of 379 experts. This web-based survey was designed using the UBC Survey Tool and all the data collected from the survey was preserved on secure UBC server. Best-practices and priority order collected from survey was classified into small cities and large cities following CUTA classification. Validity and reliability tests were conducted to check the questionnaire quality and to generalize the sample responses to complete population, respectively.

To cover the second limitation of literature, in third phase of research, uncertainties related to transit stop planning were classified and a tri-level tri-modular index-based decision-support tool was developed, called TRANsit Stop inDEX (TRANSDEX). TRANSDEX was developed using fuzzy synthetic evaluation and analytical hierarchical process. TRANSDEX is a tri-level tri-modular decision-support tool with takes field inputs of transit stop at first level, prioritization inputs at second level, and generate results at third level. First module of TRANSDEX eValuate an Existing transit sTOP (VETOP) and generate result in the form of an index which range from 0 to 10. Second module of TRANSDEX provide recommendation to imProve an Existing transit sTOP (PETOP) and generate result in the form of two charts. Third module of TRANSDEX allocate NEw transit sTOPs (NETOP) along a street. This module works on an algorithm which first locate a large number of transit stops along a street, then eliminate those stops having least VETOP value and check spacing constraint to continue or terminate the algorithm. The developed tool was then used to evaluate 2 transit stops and allocate new strops along a street to demonstrate the application of tool.

1.6 Research Outline
This thesis consists of six chapters. Chapter 1 introduces the background and motivation for research along with research goals and objectives, and thesis outline. Chapter 2 reviews the literature on transit stop planning, the controlling factors which effect transit stop planning, different models developed, and their limitations. Chapter 2 also discusses the expert opinion survey, its design, validation tests, and reliability tests. To solve uncertainties, the Fuzzy Set Theory (FST) is also discussed and the steps for fuzzy synthetic evaluation are explained. The
multi-criteria decision-making methods for aggregation step of fuzzy synthetic evaluation are also discussed in this chapter. Chapter 3 discusses the methodology adopted in this research study. Chapter 4 presents the procedure adopted to define different factors and indicators, and classification of uncertainties related to the transit stop planning process. Chapter 5 describes the expert opinion survey, its instrument design, validity test results, reliability test results, and survey data analysis procedure and results. Chapter 6 explains the transit stop index tool, its development, and application for evaluating existing stops, improving existing stops, and allocating new stops. Chapter 7 concludes the thesis and discusses contributions, limitations and pathway for future research.
Chapter 2: Literature Review

2.1 Outline

This chapter presents the literature review of this research. Section 2.2 discusses reasons of ridership decline. Section 2.3 highlights the importance of transit stops in improving ridership and reviews previous transit stop planning research efforts. Section 2.4 presents the expert opinion survey. Section 2.5 discusses the Fuzzy Set Theory and fuzzy synthetic evaluation to deal with the uncertainties associated with transit stop planning. Section 2.6 is about the different aggregation methods used in fuzzy synthetic evaluation. Section 2.7 concludes the literature review.

2.2 Decline in Ridership

Back in the 1980s, transit systems in Canadian cities were superior to their counterparts in the United States because of the integrated transit land use planning approach. This integrated transit land use planning resulted in uniform densities in areas rather than dispersed densities which further enhanced the transit efficiency. The state and federal governments actively played their role to advance transit by providing adequate funding, extensive routing of service, and controlling sale and parking of autos. The incorporation of new technologies into the transit system like energy efficient and environmental friendly Advanced Light Rail Transit (ALRT) or Intermediate Capacity Transit Systems (ICTS - which is a blend of traditional heavy rail and LRT), automatic train control, less expensive stations (which include bright red frames, weather protected modular shelter, variety of public information items like schedule and telephone enquiry) coupled with high technology of ALRT enriched the transit system. System interface was improved to improve ridership. New neighborhoods were developed with promotion of mixed land use and were connected to main city through high level of service transit system. The fare system was regularized through passes and coupons which make it easier for buses to catch their schedule besides maximum fare collection. Overall, Canada was light-years ahead than most of other nations and was open for new ideas and new innovations (Cervero 1986). Till date, sustainable urban growth in Canada is in hands of efficient, reliable, and affordable public transit. However, now the public transit system is suffering from many factors like lack of funds, uncontrolled auto sale resulting in traffic congestion, and uncertain passenger loading variation.
This all leads to reduction in transit efficiency, level of service, passenger comfort and security, and ultimately ridership (Chen et al 2011).

From 1950 to 1990, car ownership and transit ridership increased side-by-side as shown in Figure 2-1(a) and Figure 2-1(b). During the period from 1950 to 1960, government spent more money in transit infrastructure like subway line in Toronto and Montreal metro system. In 1980s, the investment of Canadian government resulted in high ridership which was on par with European countries (Soberman 1983). But after 1990, transit ridership decreased sharply, as shown in Figure 2-1(c). This decrease was partly due to the lack of government support towards transit and reorganization of car manufacturers on global scale. In 1991, Canada reduced the tax on buying new car by 5.5%. Other economic factors like fluctuation rate and high buying capacity also contributed towards more auto purchases. In public transit, productivity and innovation did not go hand-in-hand as were in case of auto-mobile industry. The auto industry flourished at the cost of transit and consequently transit began to suffer in terms of funds in both ways, low ridership and less government funding due to the greater deficit. To cover this, the fare of transit was increased at the time when auto prices went down as shown in Figure 2-1(d). This trend resulted in more car ownership and less ridership which led to more road congestion. For example, in Kelowna BC, in 2013, only 4.3% trips were made by public transit compared to 82.2% trips made by personal autos (Okanagan Travel Survey 2013). Due to low ridership, the operating subsidy per passenger trip from origin to destination rose from $0 in 1970 to $0.87 in 1992 while revenue covering just over half of cost i.e. 53% (Perl, A. and Pucher 1995).
All the above factors consequently led to decline in productivity of public transit by 1.2% per year from 1986 to 2006. While the rail rates decreased by 2.2% per year, airline fares dropped by 1% per year, truck rates went down by 1.4% per year, transit was the only exception showing a rising trend of 1.7% per year in fares. The compound annual growth rate was decreased by 1.2% for public transit from 1986 to 2006. The annual fare was increased by 4.2% per year (Conference Board Canada 2009) which resulted in further decrease in ridership because every 3% increase in fare further decrease the ridership by 1% (Litman 2004).

The most promising way to increase ridership is to place transit stops near commercial areas where jobs are located instead of placing them near residence areas. It is observed that the density required to place transit stop near job locations is half of the residences, generating same revenue. Similarly, the catchment areas i.e. walking distance and buffer region of transit stops of residential areas (half mile) also differ from commercial areas (quarter mile) (Cervero and Guerra 2011). A transit stop is the first connection between passenger and transit. It greatly influences transit providing agency operational issues and passenger perception of riding quality (Xin et al. 2015). Transit stops ensure the intermodal transfers and facilitate the passengers in paying fares. It results in a decrease in dwell time which led to better travel time for transit (APTA 2010).
2.3 Transit Stop Planning

Transit stops serve as a pivot point between transit system and passenger. According to the Transit Cooperative Research Program (TCRP 19), transit stops play a very important role in improving transit system performance and maintaining traffic flow, passenger safety and security. In public transportation system, transit stops are the center of gravity for consolidation and transmission for traffic flow system (Sung and Jin 2001). For effective transit system, the transit stop is a crucial point because this fundamental facility provides switching point for inter-model flows and enhances a linear stream pedestrian flow (Yu et al. 2007). Public transport is best located where the passenger demand is high, transit users have park and ride facility and pedestrians can have easy access. All these factors encompass the transit stop planning and are called public transportation compatible. Public transportation compatible also includes the land use planning effects on the road network (George 2000).

The spatial factors, which include both spacing between consecutive transit stops and location of a particular transit stop, are important for proper transit stop planning (Foda and Osman 2010). A transit stop location which offers minimum cost of transit system and residents’ travel are key issues for location selection (Hua and Rongguo 2013). Public transit stop planning is a complex task which starts from problem diagnoses, solution analysis, narrowing demand and supply gap and implementing it all. One of the criteria is service coverage which is directly dependent on the spacing between two consecutive transit stops (Huang et al 2008). The spacing of transit stop is important because the total time of transit is divided into three parts, transit online travel time, transit stopping or dwelling time, and transit terminal time. Among these, the stopping or dwelling time is dependent on the transit stop spacing. In European countries, the transit stops are placed not so close to obtain a faster travel time whereas in U.S.A., the transit stops are placed close to each other. According to a research made on U.S.A. stops, if half of the transit stops are eliminated, the transit total time can be enhanced and agency profit can be saved (Minnpost 2016). The spacing of consecutive transit stops is important for minimizing transit running time, transit stop time, passenger access time and fleet size (Feder 1973). According to a research, adequate stop spacing can improve the transit running time by 6% (El-Geneidy et al. 2006). Vehicle emissions, passenger travel time, operating time and fleet size are all affected by transit stop inter-spacing (Gong et al 2011). While deciding the inter spacing of transit stops;
space constraint, interaction between traffic, efficient use of available resources, and walking time of passenger are important factors for a rational distribution of transit stops (Alonso et al. 2011). Among others, percentage covered by transit stops is also an important factor to decide interspacing (Diab and El-Geneidy 2012).

Besides location and interspacing, the design of transit stop also relates to the overall performance of transit system. For example, lack of convenience for transit user at transit stop results in more complaints and consequently unreliable and uneconomical transit system. These include time table, fare table, telephone enquiry bureau, real-time information about service, passenger information system, vehicle location system, and passenger comfort (Clowes 1996). A proper transit stop design improves rider satisfaction and gives a perception of shorter waiting time, which leads to greater ridership. According to an estimate, in Vancouver BC, Canada, the improvements in transit stop design can increase the ridership by 45% (Zhang 2012). Transit stop design is important because commuters spend a large amount of time in waiting or transfer and if the comfort of commuters at that time is enhanced, it results in an increase in ridership generating more profit for the transit agency (Taylor et al. 2009).

2.3.1 Limitations of Mathematical and Simulation Models
Numerous approaches, based on pure mathematical techniques, have been developed to examine the effect of transit stop interspacing and location on various factors. In general, the results of the previous studies suggested that transit routes with suitably spaced and located transit stops have faster travel times and are more economical to operate.

Optimal location model for transit stop was proposed to minimize total travel time. In this model, arterial link speed was considered twice of branch link. Further, stop capacity was not taken into account and the transfer time between the stops was assumed to be zero (Yu et al. 2007). A programing based approach was proposed in which a non-stop service was considered in predetermined zones. But in this approach, for each zone, only one stop was chosen. Also, as of optimal location model, stop capacity was not include in this model. This model was called Cluster Hub Location Problem (CHLP) (Wagner 2007). The limitations of CHLP were addressed and a new model, Mixed Integer Programming (MIP), was formed which were then used to solve
warehouse location problems (Erlenkotter 1978) and stop location problems (Klincewicz 1996) (Mayer and Wagner 2002). But without applying pre-processing techniques, MIP was slower in practice (Wagner 2007). Transit system reliability and performance parameters were expressed as punctuality index based on routes and deviation and evenness index based on stops (Chen et al. 2009). Several researchers have developed transportation model like quantitative analysis of land-use under different conditions (George 2000), analytical GIS space technology (Du Jinkang 2004) (Feifei 2011), hierarchical procedure for public traffic design (Zheng-Wei et al. 2009), Voronoi diagram method (Novaes 2000) (Hua and Rongguo 2013), and multiline transit stop capacity analysis (Jing 2010). Factors used in modelling include passenger access time and transit travel time (Mei et al. 2007), passenger access cost and transit travel cost (Gao et al. 2009), and transit speed (Moura et al. 2012). Based on Voronoi diagram, six most important factors were studies which include land layout within transit stop catchment, travel distance to transit stop, layout position of transit stop, impact of other buses sharing same stop, traffic volume on road section and traffic direction at transit station (Hua and Rongguo 2013).

Apart from mathematical models, simulation models have been adopted (Moura et al. 2012). Parallel Stop Simulation (PASSION) was developed to compute transit stop capacity and related impacts and to study the interaction between transit, passengers and traffic at transit stop (Fernandez 2007) (Fernandez 2010) (Fernandez 2001) (Fernández 2003) (Fernandez and Planzer 2002). PASSION was developed to overcome the limitations of Integrated Resources for Evaluating Numerical Estimates (IRENE) (Gibson 1996) (Gibson et al. 1989). The limitations of IRENE were its lack of ability to study the effects from factors that impact transit user like waiting time and transit stop density (Fernandez 2010). Other simulation models proposed were Micro Simulation of TRANSIT (MISTRANSIT) which studied public transport vehicle, passenger presence and their interaction (Fernandez et al. 2010) (Cortés et al. 2007), Transit Special Interest Group on Simulation and Modeling (TransitSIGSIM) which gave a more detailed interaction between transit and passenger (Silva 2001) (Tyler et al. 2002), HETEROscedastic Single-Index Model (HETERO-SIM) which took into account the interaction between transit stop and traffic flow (Koshy and Arasan 2005) and CORridor for TRANSITes (CORTTRANSIT) which simulated the guided transit, articulated transit and conventional transit running on a segregated way (Valencia and Fernandez 2011). AutoMOD software simulation
was used for transit stop queuing system based on transit flow rate and number of berth of transit station (Ruan et al. 2010). AutoMOD was composed of AutoMod, AutoStat and AutoView. AutoMod was more realistic based module. For advanced statistical simulations, AutoStat was used. AutoView was used to have more advance animated simulation graphics interphase (Jerry 1984). In this simulation, only two variables were used to decide the number of berth, i.e. number of transit units and transit flow rate (Ruan et al. 2010). However, transit operational routes, transit departure interval at start stop, variation in transit travel time and transit staying time at transit stop also contribute to the decision of number of berths. The number of transit berths is directly related to network route design, setting time table and scheduling vehicles to trips (Li et al. 2011).

A major drawback of such approaches based on pure mathematical and simulation techniques is that they tend to oversimplify the complexity of the problem by focusing only on a few factors and neglecting their correlation and the uncertainties associated with them. For example, Murray (2003) investigated the effect of stop locations on transit service coverage which aimed to provide public transit to 90% of the population within 400 metres access. However, considering a 400 m walk as a suitable transit stop access threshold without taking into consideration the effect of slope, temperature and transit user age can be misleading. In fact, 400 m might be a long distance to walk on a steep gradient in snowy conditions for a person of age 60. Similarly, the population coverage of 90% is also uncertain because population coverage by transit in Toronto is 81.2% and in Melbourne is 77.6%. Population coverage of other modes is given in Table 2-1 below.

<table>
<thead>
<tr>
<th>Mode</th>
<th>2006 Toronto TTC</th>
<th>2006 Melbourne Transit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transit</td>
<td>81.2</td>
<td>77.6</td>
</tr>
<tr>
<td>Streetcar</td>
<td>16.4</td>
<td>42.4</td>
</tr>
<tr>
<td>Subway/Train</td>
<td>20.7</td>
<td>32.2</td>
</tr>
<tr>
<td>All Modes Total</td>
<td>84.4</td>
<td>96.7</td>
</tr>
</tbody>
</table>
Similarly, other researchers also studied individual effects of factors on transit stop location without considering their correlation. For example, Alonso et al. (2011) only studied traffic congestion, Gao et al. (2009) studied uneven distribution of passenger flow and Hafezi and Ismail (2011) studied interaction between transit and traffic. However, in practical situation, at a transit stop, interaction of traffic and transit is more due to traffic congestion and uneven passenger demand. Therefore, the super imposed effect of all factors must be studied.

In another paper, Furth and Rahbee (2000) used dynamic programming and geographic modelling to determine optimal transit stop spacing and subsequently optimal transit stop locations. In their model, they studied riding time, operating cost, and walking time. However, they completely neglected the land-use effects whereas the type of land-use directly affects the walking time and buffer distance. They also did not consider the demographics and geological differences of the area.

2.3.2 Limitations of Transit Agency Manuals

In transit manuals, the guidelines for transit stop spacing and location differs which adds uncertainty in the transit stop planning. For example, according to best-practices in transit service planning (Center for Urban Tranportation Research 2009), the transit stop is desirable for a household of 200 or more. However, according to Orange County Transportation Authority (OCTA 2004), a transit stop is desirable for a household of 500 or more. Similarly, according to BC Transit Guidelines (2010), the transit stop spacing for urban area is in a range of 200m to 365m. However, according to Southeastern Pennsylvania Transportation Authority (SEPTA 2004), a transit stop can be placed no more than 150m in an urban area. Regarding the gradient of road at which transit stop has to be placed, BC Transit (2010) recommends a maximum of 8% because after this, the wheelchair maneuvering become difficult. But according to a research conducted by Furth and SanClemente (2006), a gradient of more than 4% should be avoided. These differences in guidelines add complexity in transit stop planning.

The design of transit stops is an important element that affects passengers’ perception. Transit stop design refers to the layout, configuration, and amenities of the stop. Horizontal and vertical gaps between the transit and the platform are important considerations in transit stop design.
According to Operational Impacts of Transit Stops (Tyler et al. 2002), if the horizontal gap is less than 50 mm, it is said to be in perfect range. If it exceeds 50 mm and still is less than 100 mm, it can be accessible but with a little difficulty. And, if it is more than 100 mm, then is not accessible at all. However, National Association of City Transportation Officials (NACTO 2016) does not give any such categories and simply says that it should be less than 76 mm. In another study, it was found that horizontal gap can go up to 300 mm (Dejeammes et al. 1999). Taking vertical gap into consideration, the guidelines from operational impacts of transit stop stands still whereas NACTO (2016) limits it to less than 16 mm.

Another limitation of transit stop manuals is the unavailability of correlation among any factor. The transit manuals like TCRP 19 (Jacques and Levinson 1996), TCRP 100 (Hunter-Zaworski 2003), TCRP 26 (Jacques and Levinson 1997), BC Transit (2010), Best-practices in Transit Service Planning (Center for Urban Tranportation Research 2009), Southeastern Pennsylvania Transportation Authority (SEPTA 2004), Orange County Transportation Authority (OCTA 2004), provide guidelines regarding factors but did not provide practical condition rating of these factors. For example, it is not provided in any guideline that either vertical gap is more important or horizontal gap is more important. Similarly, three options are given to provide information provision i.e. static schedule information, real time information and information map. But in no literature, it is provided that which option is best to apply followed by others. Similarly, according to TCRP 19 (Jacques and Levinson 1996), factors like transit stop width, waiting time, weather condition, sidewalk width, and distance of fire hydrant tank must be consider in providing seats at a transit stop. But like all other, they did not provide any ranking or prioritization of these factors. The lack of prioritization and ranking, in all these examples discussed above, effectively reduce the efficiency of a transit stop.

Another difficulty is that these guidelines did not give best-practices for all factors related to transit stop which makes it difficult for decision makers to decide on a particular facility. For example, taking the above stated example of seats, TCRP 19 (Jacques and Levinson 1996) does say that these factors are important in order to decide the seat provision but it did not say anything on how much waiting time should be to provide the seats or how adverse weather conditions should be to provide the seats. Similarly, BC Transit (2010) provides a range of
amenities which may be provided at a transit stop like passenger landing pad, wheelchair landing pad, curb letdown, transit stop sign, transit shelter, seating, bicycle storage, lighting, real time schedule, camera, telephone, and newspaper or vending boxes. But it neither gives any prioritization or ranking for any of them nor best-practices for most of them. For example, it did not say anything about when to provide transit stop lights, CCTV camera, telephone, newspaper, or vending boxes.

2.3.3 Uncertainty Analysis

In spite of dealing with uncertainties in both long-run and short-run decision in transportation planning; analysts, planners, and decision-makers do not explicitly consider uncertainties in the evaluation and design of transportation options at local, provincial, and national levels. Furthermore, no systematic framework is available to identify and categorize uncertainties in major transit decisions (Mahmassani 1984). Uncertainty can be associated with any parameter, factor or activity which is involved in evaluation of alternative transport options. In transit stop planning, uncertainties exist in selecting modelling factors, their acceptable benchmark level and predicting the required number of transit users. The presence of uncertainty means that if the alternative A’ was selected at time T’ under the knowledge and understanding about future time T’+ΔT, it may be realized at time T’+ΔT that alternative A’’ which was not selected at time T’ was more desirable according to the prevailing conditions at time T’+ΔT (Mahmassani 1984).

Broadly, uncertainties can be categorized as descriptive uncertainties and measurement uncertainties. While descriptive uncertainty can originate due to lack of understanding or representation of a system to the external environment, measurement uncertainty can be due to the inaccuracy of mathematical or simulation model or statistical techniques used. Although both seem to be quite distinct, yet they can be mutually inclusive in nature (Rowe 1975).

Mahmassani (1984) in his article, “Uncertainties in Transportation Systems Evaluation: Issues and Approaches”, classified uncertainties into the following five different categories:

- First were the unknown situations directly effecting transportation decisions, such as political unrest or break-through in technological advancements. These could be forecasted to some extent but cannot be predicted deterministically.
• Second were the unknown situations indirectly effecting transportation decision, such as economic or social circumstances like budget restrictions or high auto ownership levels, and development of suburbs leading to high travel demand in connecting facilities.
• Third was related to the predicted impacts resulting from modelling activity. These could be due to lack of knowledge about the phenomena being modeled, lack of knowledge about input data, or approximation of model. This category also included demand estimate, approximation in traffic flow, benefits measured or cost estimated.
• Forth was the vagueness in criteria definition like difference of opinion between transportation planner’s due to qualitative judgement.
• Fifth was related to the preferential treatment towards some alternative for evaluation. For example, whether to include certain factor in modeling or not (which might be due to lack of available information about factor or lack of lack of knowledge of decision maker).

The quantification of the above stated uncertainties, in context of transit stop planning, is a complex task. To include uncertainty, optimality index was formed based on mean, variance, and probability of minimum possible time and the variance of path from minimum possible time (Kamburowski 1985). Planning with uncertainty is different from classical planning in terms of quality and quantity of information known at the time of planning or execution (Bonet and Geffner 2000). The Canadian Traveler Problem, a transportation planning problem, is a subset of optimization problem in which some details are known while solving the problem while others are partially known which leads to uncertainty. In everyday life, transit operation is effected by uncertain conditions like unexpected delays, traffic congestion, random passenger demand, irregular flow rate and incidents. At planning level, the key factors have to be designed which include uncertainty related to temporal and special distribution. These uncertainties in system conditions, average values of passenger demand and traffic congestion, results in inefficient operational scheme. On every day basis, decisions have to be made by decision makers. Due to large number of factors involved in transit stop planning, it is not possible to find the adequate solution manually. Therefore, a decision support system is necessary for making decisions based on site specific data (Borne et al. 2003). Decision support tools are used to solve complex
decisions and problems. Decision-making involves how decisions are taken, how they can be made better and more successfully taken (Roy 1993).

To solve the uncertainties, different techniques were applied. For example, stochastic programing approach considered the input as random variable with its random probability distribution. Random probability distribution of transportation variables is difficult and expensive to obtain. Therefore, robust optimization approach was formulated to optimize decisions under uncertainty. Unlike stochastic, the input was not random variable but varied within a boundary set. The worst case was chosen within the boundary set for optimization. Sometimes, the worst case optimization makes the problem overly conservative (Kulshrestha et al. 2014). Multi-agent approaches were proposed to solve the diverse transportation engineering problems (Kulshrestha et al. 2014) (Borne et al. 2003) (Fayech et al. 2002) (Gruer et al. 2001) (Laichouret et al. 2001). For example, considering a large number of decision factors and uncertainty associated with them, an evolutionary rescheduling algorithm was designed based on cooperation between multi-agent and evolutionary approach (Borne et al. 2003). A similar multi-agent decision support system was designed to assist in decisions regarding transit traffic disturbance involving a supervision module and regulation module (Fayech et al. 2002). Two major drawbacks of using multi agent approaches are unpredictable pattern and outcome of interaction; and difficulty in predicting the outcome of overall system based on constituent components (Jennings 2000). Other limitations of agent based approaches include security of application, modularity, framework/component approach, agent’s intra-commination, agent’s service constraints and agent’s accessibility constraints (Ferber et al. 2003).

The interdependency and uncertainties associated with most of the presented location, interspacing and design factors result in inefficient transit stop planning. Further, none of the transit agency manual gives guidelines in relation to the city population. The use of generalized guidelines in both small and large cities results in over-or-under designing of transit stops. The limitations of published literature and transit agency guidelines, as explained above, can be summarized as;

1. Lack of best-practices according to city size for street transit stop planning.
2. Differences of best-practices of factors for street transit stop planning.
3. Lack of prioritization of factors for street transit stop planning.
4. Lack of decision-support tools incorporating uncertainty analysis in street transit stop planning.

Surveys are the best method to collect information about a specific topic from a sample of individuals. It requires little effort to gather information in a systematic manner and then tabulating the responses to draw useful conclusions. The surveys are so designed that same set of questions are asked to different individuals to cover the diverse population for more accurate results (Fonouniolasl 2016). Following section deals more about the surveys, their design, and implementation.

Fuzzy set theory is important for solving nonlinear problems which involve ambiguity and vagueness (Zimmermann 2011). Many problems in field of transportation are ill defined, uncertain and overlapping with each other. Subjective judgment is present in making decisions regarding choice of route, transportation mode, driver’s perception and reaction, perception of transit user regarding level of service and defining safety standards. All deterministic and stochastic models developed to deal with such problems are binary in nature which does not deal effectively with these situations. Therefore, fuzzy set theory is used that recognize the vague boundary between parameters (Maiers and Sherif 1985). Section 2.5 deals with the fuzzy set theory and its applications.

2.4 Expert Opinion Survey
To collect detailed information about a specific topic in an organized manner, quantitative or qualitative surveys are the most common tool. Quantitative surveys are useful for capturing the diverse factual opinion, and hence, the sample size is of prime importance. However, qualitative surveys are more concerned with attitudinal diversity, and therefore, sample size is not of much importance. Yet, a range of 15-30 or 20-30 samples is recommended (Masoud 2015). The type of questions being asked in a survey is classified into two classes; direct questions and attitudinal questions. Direct questions are more of the factual nature and can be open-ended or closed-ended. Attitudinal questions are more related to opinion of the respondent and mainly asked in form of Likert scale or semantic differentials (Masoud 2015). Open ended questions are thought to be better than closed ended questions because of two main reasons. First, in closed ended questions, one cannot respond according the simultaneous response one may have. Second, the closed ended
questions inculcate the biasness into the survey in a way that respondent can only choose from the list being offered by the investigator. However, the open ended questions need extensive coding for data analysis and also, the response rate for open ended questions is low (Reja et al. 2003). However, this difference of closed ended and open ended questions was resolved to a greater extent when Lazarsfeld (1944) suggested to use open ended questions in start, and code the survey in a way that by analyzing the results, it automatically show a closed ended list to increase response rate. In attitudinal questions, another way of survey development is using Likert scale or semantic differentials to capture qualitative data, like opinions regarding importance of factors. Attitude is a bi-dimensional element, which include direction and strength. Direction can be positive or negative towards the subject whereas strength is the intensity that by how much degree the respondent agree or disagree (Albaum 1997). Likert scale is a psychometric scale consisting of several categories from where the respondent picks the desired one. It is mostly closed ended question type with a scale ranging from 0 to 5 or 0 to 9, depending on the ease of respondent (Nemoto and Beglar 2014).

Pilot survey, which improves the credibility of data, is mostly neglected because of lack of time or money. If the survey instrument design is appropriate, pilot survey is not expected to make many changes and thus, the results of pilot survey can be merged with the main survey. Even if pilot survey detects some changes to be made, it will save the cost of errors occurring in main survey. In addition to survey instrument design, pilot survey is also an opportunity to check other options which will be beneficial for main survey, for example, the length of survey or working of survey. Any redundancy detected in survey questionnaire during pilot phase can be removed from the main survey. For example, in pilot survey of a study, it was found that the respondents feedback for longer version was better than the shorter version, which is counter-intuitive (Richardson et al. 1995). Besides above stated benefits, pilot survey is also beneficial to check the sampling frame adequacy, variability inside target population (homogeneous or heterogeneous), estimation of non-response rate, improving the data collection method and layout of questionnaire, methods of data entry and result analysis, estimation of cost and duration of main survey, and efficiency of survey organization. Pilot survey may suggest some additional questions to be added for final result generation. Variability within target population can only be judged from the pilot survey. However, one cannot completely rely on the pilot survey because it is on a smaller scale. Similarly, the response rate can be estimated from pilot to calculate the
sample size and appropriate measures can be taken to decrease the non-response rate. A very low response rate and difficulty of collecting the required data indicate some fault in data collection method. Color and contrast can be adjusted to make layout more user-friendly.

Size of pilot survey depends on the resources allocated for pilot. Usually, five to ten percent of survey budget is allocated for the pilot survey (Richardson et al. 1995). Pilot sample size should not be too large as that of main survey, however, it should cover the variability and should represent the target population. If appropriate, as discussed above, the results can also be merged with the main survey results.

2.4.1 Survey Design
The target population is the population about which information is to be collected. Sampling units may be people, vehicles, households, or any other discrete unit. It is important to detect the clear survey boundary and form a sampling frame. It is important to define the survey boundaries to clearly detect the survey population. Sampling frame is a list of information of all, or nearly all, population being included in the survey. Survey frame can be email address, mailing addresses, telephone directory, geographical maps, electoral rolls, census lists, society membership lists, or any other such contact list (Richardson et al. 1995). Most of the times, it is not possible to collect data about whole population or it is unnecessary, therefore, out of population, sample is extracted so that it is the true representation of the entire population. The accuracy of results obtained from sample calculations is dependent on the sampling method. Random sampling technique is most commonly applied which is based on the selection of each unit independent of another and having equal probability of selection. Different random sampling methods being applied in field are simple random sampling, stratified random sampling, variable fraction stratified random sampling, multi-stage sampling, cluster sampling, and systematic sampling (Richardson et al. 1995).

Expert opinion surveys need particular consideration because their target population is not as large as in case of household surveys or individual surveys. Furthermore, the variation in response rate (RR) of expert opinion surveys is very significant. For example, RR for studies conducted on individuals was found to be 52.7%. Similarly, RR for organization was found to be
35.7% (Baruch and Holtom 2008). Miyashita et al. (2007) conducted their expert opinion and reported their RR to be just 16%. Similarly, Whitfield et al. (2008) reported their RR to be 20.5%. Literature on expert surveys show huge variation in number of observation recorded. Table 2-2 below shows a review of 20 articles published after 2005 with an average of 76 complete responses that vary from a minimum of 15 to maximum of 249 responses. Web based surveys are becoming more popular due to less energy consumption and cost efficiency. At the same time, instrument design of survey is very important to obtain an unbiased result from respondents. Because in the absence of the interviewer, the instrument keeps the respondent motivated and provide guidance on how to answer questions (Ware 2000). In web design, the variety of objects, colors, graphics and pictures available to complement the original question, may facilitate or distract from the final completion of survey (Redline and Dillman 1999).

Table 2-2: Stats about Past Literature Consulted to Detect Sample Size

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Study</th>
<th>Population Size</th>
<th>Sample Size / Replies Received</th>
<th>Response Rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(Therriault and Herborg 2008)</td>
<td>520</td>
<td>132</td>
<td>25.38</td>
</tr>
<tr>
<td>2</td>
<td>(Buchholz et al. 2009)</td>
<td>137</td>
<td>46</td>
<td>33.57</td>
</tr>
<tr>
<td>3</td>
<td>(Man et al. 2016)</td>
<td>N/A</td>
<td>53</td>
<td>N/A</td>
</tr>
<tr>
<td>4</td>
<td>(Steenbergen and Marks 2007)</td>
<td>N/A</td>
<td>116</td>
<td>N/A</td>
</tr>
<tr>
<td>5</td>
<td>(Christopoulos 2010)</td>
<td>N/A</td>
<td>15</td>
<td>N/A</td>
</tr>
<tr>
<td>6</td>
<td>(Hol et al. 2012)</td>
<td>78</td>
<td>31</td>
<td>39.74</td>
</tr>
<tr>
<td>7</td>
<td>(Rabiser et al. 2010)</td>
<td>55</td>
<td>28</td>
<td>50.91</td>
</tr>
<tr>
<td>8</td>
<td>(Warwick 2005)</td>
<td>731</td>
<td>163</td>
<td>22.23</td>
</tr>
<tr>
<td>9</td>
<td>(Malley 2007)</td>
<td>413</td>
<td>249</td>
<td>60.29</td>
</tr>
<tr>
<td>10</td>
<td>(Chakrabarti 2010)</td>
<td>N/A</td>
<td>33</td>
<td>N/A</td>
</tr>
<tr>
<td>11</td>
<td>(Cheung et al. 2008)</td>
<td>81</td>
<td>76</td>
<td>92.82</td>
</tr>
<tr>
<td>12</td>
<td>(Didier et al. 2007)</td>
<td>83</td>
<td>42</td>
<td>50.60</td>
</tr>
<tr>
<td>13</td>
<td>(Elmer et al. 2010)</td>
<td>98</td>
<td>55</td>
<td>56.12</td>
</tr>
<tr>
<td>14</td>
<td>(Klode et al. 2011)</td>
<td>N/A</td>
<td>70</td>
<td>N/A</td>
</tr>
<tr>
<td>15</td>
<td>(Otto and Reichert 2010)</td>
<td>38</td>
<td>19</td>
<td>50</td>
</tr>
<tr>
<td>16</td>
<td>(Gattuso et al. 2013)</td>
<td>N/A</td>
<td>53</td>
<td>N/A</td>
</tr>
<tr>
<td>17</td>
<td>(Escorpizo et al. 2011)</td>
<td>201</td>
<td>151</td>
<td>75</td>
</tr>
<tr>
<td>18</td>
<td>(Molsberger et al. 2008)</td>
<td>N/A</td>
<td>18</td>
<td>N/A</td>
</tr>
<tr>
<td>19</td>
<td>(Virgi et al. 2015)</td>
<td>379</td>
<td>95</td>
<td>25</td>
</tr>
<tr>
<td>20</td>
<td>(Masoud 2015)</td>
<td>73</td>
<td>36</td>
<td>49.31</td>
</tr>
</tbody>
</table>

Average: 76  48.53
2.4.2 Survey Validation Test

Survey validity is a measure of the degree up to which survey measures what it claims to measure. It is important because it ensures that the researcher is using questions that actually measure the issue of importance (Trochim 2002). More than 35 different types of validity terms are used but three most important validity types are content validity, construct validity, and criterion-related validity (Lynn 1986). However, criteria-related validity can be considered as a sub-category of construct validity (Trochim 2002). Therefore, two major classes of validity (i.e. content and construct) are discussed below.

2.4.2.1 Content Validity

Content validity can be defined as the degree to which the survey has factors related to the problem being solved. As described by Polit and Beck (2006), content validity is evaluated through judgement in two different phases;

1. A priori efforts: These are made by the survey developer through literature review and considerations put in grouping items together to form a connecting network.

2. A posteriori efforts: The survey respondents judge the factors presented in survey after putting enough thoughts to complete the survey.

A priori efforts, also termed as Stage – 1 or development stage, is further decomposed into 3 sub-stages (Lynn 1986):

a) Domain identification: This step is directed towards the collection of all the relevant factors and items which can affect the problem in question.

b) Item generalization: All the factors and items collected in Step (a) are grouped so that they form a meaningful network.

c) Instrument formation: All the factors are translated into survey design so that it looks presentable to the respondents.

A posteriori efforts, also termed as Stage – 2 or judgement quantification stage, is further decomposed into 2 sub-stages (Lynn 1986):

a) Judgement of content validity of factors/items: Factors or items presented in the survey are judged that whether they are those affecting the problem under question.
b) Judgement of content validity of instrument: The instrument design of survey is judged based on the ease of respondents to fill the survey.

Out of these two phases, second phase has gained much importance. Numerous mathematical methods for quantifying expert judgement have been proposed which include average expert rating using pre-established criteria for acceptability, coefficient alpha, multi-rater kappa coefficient, and content validity index (CVI). CVI is normally collected using a 4-or-5-point Likert scale ranging from not relevant to highly relevant. CVI is calculated as a ratio of number of experts agreeing to the total number of experts, as shown in Equation 2-1 (Polit and Beck 2006).

\[
CVI = \frac{\text{Number of experts agreeing}}{\text{Total number of experts}}
\]

Equation (2-1)

Quantification of content validity is another issue which is discussed very often and was partially solved by (Lynn 1986). Lynn (1986) argued that although it is favorable to take opinion from a minimum of ten experts but, minimum of five experts is sufficient to draw conclusions which might even be reduced to three in some exceptional cases where it is difficult to locate five experts, however, drawing conclusions based on only two experts should be avoided. After selecting number of experts, it is also important to record number of experts agreeing on a specific factor or item. This can be calculated through proportion of experts who might agree to the total number of experts and then setting standard error of proportion to mark the cut-off for chance versus real agreement. Lynn (1986) presented a table which provided limits for the proportion after which the survey content can be called valid, and is reproduced in Table 2-3 below.
Table 2-3: Proportion of Experts Required to Establish Content Validity

<table>
<thead>
<tr>
<th>Number of Experts</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.67</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.50</td>
<td>0.75</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.40</td>
<td>0.60</td>
<td>0.80</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.33</td>
<td>0.50</td>
<td>0.67</td>
<td>0.83</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0.29</td>
<td>0.43</td>
<td>0.58</td>
<td>0.71</td>
<td>0.86</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.25</td>
<td>0.38</td>
<td>0.50</td>
<td>0.63</td>
<td>0.75</td>
<td>0.88</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>0.22</td>
<td>0.33</td>
<td>0.44</td>
<td>0.56</td>
<td>0.67</td>
<td>0.78</td>
<td>0.89</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0.20</td>
<td>0.30</td>
<td>0.40</td>
<td>0.50</td>
<td>0.60</td>
<td>0.70</td>
<td>0.80</td>
<td>0.90</td>
<td>1.00</td>
</tr>
</tbody>
</table>

The values in diagonal and just below diagonal (in dark blue zone) represent the minimum proportion of experts needed for content validity. The farther the proportion gets from the diagonal (i.e. the grey zone), the more invalid the survey content gets and the step – 1 of development stage needs to be reconsidered.

2.4.2.2 Construct Validity

Construct validity is the degree to which conclusions can be drawn from the operationalization in the study about the theoretical problems upon which such operationalization is based. Operationalization refers to the translation of a problem, idea, or construct into something more meaningful in nature to solve that problem (Trochim 2002). In other words, construct validity is a measure of the degree up to which survey instrument design can be readable and understandable by the respondents. Construct validity is further decomposed into two major types:

1. Translation or face validity
2. Criterion-related validity

Translation validity, also called face validity, refers to the degree of how well the problem, idea, or construct is translated into the survey operationalization. Is refers to the instrument design that whether it depicts what the researcher wants to say. It is a subjective measure of judging survey validity and gives the weakest measure (Trochim 2002). Face validity is very closely related to
content validity as describes above in Section 2.4.2.1. Content validity deals with the content or factors selected to develop the survey whereas face validity refers to the arrangement and instrument design of those factors. Face validity can be improved by making the instrument design more systematic. Face validity is best evaluated by those who are not directly related to the research question. If those people can understand the problem under question, it means that the face validity of survey is valid. This is typically done in pilot surveys.

Translation validity assumes that the survey developer has a wide knowledge of the survey construct and survey is based on those constructs. Whereas, criterion-related validity examines that whether the operationalization of survey is behaving in the same way as the survey developer expected them to behave. Criterion-related validity is further classified into 4 types;

a) Predictive validity
b) Concurrent validity
c) Convergent validity
d) Discriminant validity

Predictive validity is a measure of how well the operationalization of survey can predict something that it should theoretically be able to predict. For example, a questionnaire on math ability might predict the respondents’ ability to work as engineer. Concurrent validity measures the ability of operationalization to distinguish between two groups that it was expected to distinguish at the same time. Convergent validity examines the degree to which the operationalization under question is correlated to other operationalization which it theoretically should correlate to and discriminant validity examines the degree to which the operationalization under question is different from other operationalization which theoretically it should be different from. It is important to note that in concurrent validity, two groups within the same operationalization are analyzed but in discriminant validity, two different operationalizations are analyzed.

Construct validity can be calculated by many methods which include nomological network, multitrait-multimethod matrix (MTMM), or pattern matching. Pattern matching is better than MTMM because it is more flexible and general than MTMM and it does not require to measure
each construct individually using multiple methods. Pattern is any arrangement of object or entities which are non-random and can be described. For example, it is a pattern that lower limit of any range will always be different than the upper limit. Pattern matching can be judged by using any test of significance like t-test or analysis of variance (ANOVA).

T-test is the basic form of hypothesis testing, and tests if two sample frames converges to same point or remains distinct (Montgomery 2008). T-distribution shows the boundary of critical region formed on the inside edges of sample distribution. If the value of t₀ (i.e. sample t-test) lies inside of critical region, it means that the null hypothesis is accepted and the two values converges to same point. If it lies outside of critical region, it means that the alternative hypothesis is correct and the values remain distinct. The value of these critical regions depends on the sample size and α-value, also called significance level or margin of error.

The test statistics for comparing two sample frames in a random sample design is given in Equation 2-2;

\[
t_0 = \frac{\bar{y}_1 - \bar{y}_2}{S_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}
\]

Equation (2-1)

Where;

- \( y_1 \) and \( y_2 \) are the means of sample frame 1 and sample frame 2 (for example, lower and upper limits of a range)
- \( n_1 \) and \( n_2 \) are the number of observations (for example, expert opinions received)
- \( S_p \) is the standard deviation of both sample frames combined which can be calculated by Equation 2-3.

\[
S_p = \sqrt{\frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2}}
\]

Equation (2-2)

In Equation 2-3, \( n_1 \) and \( S_1 \) are the number of observations and their standard deviation.
Denominator of $S_p$ equation (2-3) is the degree of freedom (DOF) and “-2” is added to eliminate the biasness from the lower and upper limits. The null hypothesis is rejected if;

- $|t_0| > t_{\alpha/2,n_1+n_2-2}$, OR
- $|t_0| < -t_{\alpha/2,n_1+n_2-2}$

Where; $t_{\alpha/2,n_1+n_2-2}$ and $-t_{\alpha/2,n_1+n_2-2}$ represents the boundaries of critical region.

### 2.4.3 Survey Reliability Test

In every survey data, there is always some unavoidable error which is to be minimized to make data more accurate. These errors are of two types – measurement error and random error. While measurement error refers to the degree a particular instrument performs in a given population, random error is unpredictable and the major source of random error is sampling techniques. To reduce this error, sample size should be large enough which makes the survey neither practical nor feasible. This random error is solved by probability estimation. Random error can also be considered while generalizing survey results to complete population collected from a small sample. This error is solved by reliability estimation (Fink and Litwin 1995). Reliability of instrument is defined as the ability to give consistent results over many repetitions (Dare and Cleland 1994).

Reliability can be estimated through two types of coefficients; i.e. test-retest reliability coefficient for longitudinal data and internal consistency reliability coefficient for cross-sectional data. Cronbach’s alpha is the most widely used reliability coefficient for assessing internal consistency reliability (McHorney et al. 1994) (Peterson and Peterson 1994). Cronbach’s alpha is calculated by Equation 2-4 (Bland and Altman 1997);

\[
\alpha = \frac{k}{k-1} \left(1 - \frac{\sum s_i^2}{s_T^2} \right)
\]

Equation (2-3)

Where;
- $k$ = number of items
- $s_i^2$ = variance of the $i$-th item
- $s_T^2$ = variance of the total score
If all the observations are identical, then $S_T^2 = k^2 S_i^2$ and $\propto$ would be equal to 1. On the other hand, if all items are independent, then $S_T^2 = \Sigma S_i^2$ and $\propto$ would be equal to zero.

The quantification of Cronbach’s alpha coefficient is of vital importance as to what level constitutes “acceptable” or “sufficient” reliability. For this reason, as mentioned by Peterson and Peterson (1994), recommended values of Nunnally (1967) for alpha are most widely used. Nunnally (1967) categorized alpha coefficient into three classes. For preliminary research, alpha was recommended from 0.5 to 0.6. For basic research, alpha was recommended from 0.6 to 0.8 and for applied research, alpha was recommended from 0.9 to 0.95. In addition, Peterson and Peterson (1994) also reviewed eight psychology and marketing related journals from 1960 to 1992 and collected more than 4,000 articles reporting on Cronbach’s alpha coefficient. A summary of their findings is shown in Table 2-4 below.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Journal</th>
<th>Number of $\alpha$’s</th>
<th>Mean $\alpha$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>AMA/ACR Proceedings</td>
<td>113</td>
<td>0.76</td>
</tr>
<tr>
<td>2</td>
<td>Journal of Applied Psychology</td>
<td>670</td>
<td>0.79</td>
</tr>
<tr>
<td>3</td>
<td>Journal of Consumer Research</td>
<td>166</td>
<td>0.80</td>
</tr>
<tr>
<td>4</td>
<td>Journal of Marketing</td>
<td>238</td>
<td>0.76</td>
</tr>
<tr>
<td>5</td>
<td>Journal of Marketing Research</td>
<td>639</td>
<td>0.76</td>
</tr>
<tr>
<td>6</td>
<td>Journal of Personal and Social Psychology</td>
<td>724</td>
<td>0.76</td>
</tr>
<tr>
<td>7</td>
<td>Journal of Personality Assessment</td>
<td>586</td>
<td>0.77</td>
</tr>
<tr>
<td>8</td>
<td>Journal of Academy of Marketing Science</td>
<td>387</td>
<td>0.75</td>
</tr>
<tr>
<td>9</td>
<td>Psychological Reports</td>
<td>418</td>
<td>0.76</td>
</tr>
<tr>
<td>10</td>
<td>Other Journals</td>
<td>30</td>
<td>0.79</td>
</tr>
<tr>
<td>11</td>
<td>Unpublished manuscripts</td>
<td>315</td>
<td>0.76</td>
</tr>
</tbody>
</table>

### 2.5 Fuzzy Set Theory

Fuzzy set theory was introduced by Lofti A. Zadeh (1965) to deal with the uncertainty of human thoughts due to vague and imprecise knowledge. The benefit of fuzzy set theory is its ability to deal with both qualitative and quantitative data (in linguistic terms) in numerical analysis. For decision-making, it is most widely used because of incorporation of expert opinion in linguistic
For crisp membership, the numerical set is denoted as given in Equation 2-5.

\[
f(x)_A = \begin{cases} 
1 & x \in A \\
0 & x \notin A 
\end{cases} \quad \text{Equation (2-4)}
\]

where

- \( f(x)_A \) represent an unambiguous condition of belonging (\( \in \)) or non-belonging (\( \notin \)).

In fuzzy set theory, fuzziness is different from randomness as fuzziness deals with the uncertain information while randomness deals with likelihood of occurrence of an event (Ross et al. 2002). A fuzzy set contain elements which do not have any defined criterion of membership. Rather than a crisp membership (0 or 1), it contains range of memberships between 0 and 1 (Lofti A. Zadeh 1965). A set \( f(\dot{\nu})_A \) is represented in a fuzzy set theory in such a way that it represents the membership value of \( \dot{\nu} \) in an interval of 0 to 1 and if the membership is close to unity then it shows a higher membership value in function. A fuzzy set is said to be empty only if the membership function is identically zero on \( x \) (Lofti A. Zadeh 1965).

For fuzzy membership, the set is denoted as given in Equation 2-6.

\[
\bar{A} = f_A(\dot{\nu}) \in [0,1] \quad \text{Equation (2-5)}
\]

Where

- \( f(\dot{\nu})_A \) represents the degree of membership of elements \( \dot{\nu} \) in fuzzy set \( \bar{A} \).

The mathematical operations of addition, subtraction, union, intersection and compliment are applicable to fuzzy sets (Lofti A. Zadeh 1965). Elements of a fuzzy set are mapped to the universe of membership value called universe of discourse. It is given in Equation 2-7.
\[ F = (x, \mu(x)) | x \in U \]  
Equation (2-6)

Where:
- \( F \) = fuzzy set
- \( x \) = variable
- \( \mu(x) \) = membership operator on \( x \)
- \( U \) = universe of discourse

A conventional notation for fuzzy sets on the universe of discourse is given by Equation 2-8.

\[ \tilde{A} = \frac{f_A(\tilde{\upsilon}_1)}{\tilde{\upsilon}_1} \oplus \frac{f_A(\tilde{\upsilon}_2)}{\tilde{\upsilon}_2} \oplus \frac{f_A(\tilde{\upsilon}_3)}{\tilde{\upsilon}_3} \oplus \ldots \oplus \frac{f_A(\tilde{\upsilon}_n)}{\tilde{\upsilon}_n} = \sum_{i=1}^{n} \frac{f_A(\tilde{\upsilon}_i)}{\tilde{\upsilon}_i} \]  
Equation (2-7)

In Equation 2-8, the summation notation \((\oplus)\) is not the algebraic summations but it shows the collection of each element. In other words, the summation sign is not for addition but for fuzzy function union theorem (Ross et al. 2002), as discussed in Section 2.5.2.

### 2.5.1 Applications of Fuzzy Set Theory

As mentioned earlier, a major drawback of equation based crisp mathematical models is that they reduce the level of complexity, for numerical or analytical solution to the set of equations, which practically exists (Parker et al. 2003). All studies till now are based on mathematical models and consider few variables independently. Knowledge of index measurement has increased since 1980 (National Research Council US 1995). Performance indicators have been applied in field of water-supply and waste water system (Alegre et al. 2013) (Matos et al. 2003), storm drainage system (Kolsky and Butler 2002), environment management (Jasch 2000), road sector (Talvitie 1999), drainage system (Geerse and Lobbrecht 2002), sustainability of power infrastructure (Dasgupta and Tam 2005), sustainability of roadways (Umer 2015), river water quality (Chang et al. 2001), reservoir water quality analysis (Lu et al. 1999), pipe inspection (Rajani et al. 2006), risk based indexing system for disinfection of bi-product (Sadiq and Rodriguez 2004), environmental conditions (Silvert 2000), urban traffic environmental quality evaluation (Tao and Xinmiao 1998) and risk based decision-making for drilling waste discharge (Sadiq et al. 2004). It is important to combine all various independent factors relating to transit stop planning into
single index form. That single index form should represent uncertain conditions relating to transit stop planning. In order to have a quick reaction to the uncertainties, the index should predict, detect, identify and analyze the uncertain condition on way to transit stop planning (Borne et al. 2003)


In transportation engineering, the first practical traffic problem was solved by Mamdani and Pappis (1977). In their work, they use fuzzy logic controller for a single intersection located on two one-way streets. A very realistic assumption of this model was the randomness of vehicles on traffic junction. But at the same time, arrival time was assumed to be uniformly distributed. After that, several other models have been proposed based on fuzzy set theory. The uncertainties pertaining to demand at transit stop and traffic condition were analyzed to propose a fuzzy control scheme for the operation of a transit system running along a linear corridor. In high demand, total travel time through the system increases. However, they assumed the transit path to be isolated from rest of traffic which makes computational work simple (Milla et al. 2012). Teodorovic and Vukadinovic (2012) in their book on topic of “Traffic Control and Transport Planning: A Fuzzy Sets and Neural Networks Approach” has presented several applications of fuzzy set theory in transportation field. It mainly includes vehicle routing model, Fuzzy MADM for air-shuttle service, fuzzy based control of isolated signalized intersection, fuzzy traffic control system on urban express way, fuzzy MADM for route choice in urban network, fuzzy approach to vehicle routing problem under uncertain demand at nodes, fuzzy model for air traffic
flow management, fuzzy approach towards aircrew rostering problem and fuzzy based approach to vehicle assignment problem. Fuzzy logic systems were developed for transportation engineering related to trip generation, trip distribution, route choice, traffic considerations, transportation investment projects, traffic control at intersections and corridors, network control, accident analysis and prevention, level of service, vehicle and crew routing, scheduling and dispatching, air transportation and river transportation (Teodorovic 1999).

2.5.2 Fuzzy Operations

Fuzzy operations of union, intersection and complementation can be described by considering two fuzzy sets \( \tilde{A} \) and \( \tilde{Y} \) mapped on a universe of discourse \( X \). For a given element \( x \) of universe, the fuzzy function-theoretic operations are given below in Equation 2-9 to 2-11.

\[
\begin{align*}
\text{union} & : \quad \mu_{\tilde{A} \cup \tilde{Y}}(x) = \mu_{\tilde{A}}(x) \lor \mu_{\tilde{Y}}(x) \quad \text{Equation (2-8)} \\
\text{intersection} & : \quad \mu_{\tilde{A} \cap \tilde{Y}}(x) = \mu_{\tilde{A}}(x) \land \mu_{\tilde{Y}}(x) \quad \text{Equation (2-9)} \\
\text{complement} & : \quad \mu_{\tilde{A}'}(x) = 1 - \mu_{\tilde{A}}(x) \quad \text{Equation (2-10)}
\end{align*}
\]

Where;

- \( \cup \) = Union
- \( \cap \) = Intersection
- \( \tilde{A}' \) = Complement of fuzzy set \( \tilde{A} \)
- \( \land \) = Complement of fuzzy

These fuzzy operations can be more precisely explained by Venn diagram, as shown in Figure 2-2 (Ross 2009) (Ross et al. 2002). X-axis shows the universe of discourse and y-axis shows the membership values of fuzzy sets. Blue shows the membership function of \( \tilde{A} \) and red shows the respective membership function of \( \tilde{Y} \). The complement of \( \tilde{A} \) is shown by blue dots in Figure 2-2(d).
2.5.3 Features of Membership Functions

All information about a fuzzy set is represented by membership function (Ross 2009). Core of the membership function of fuzzy set $\tilde{A}$ is the region of universe of discourse where membership is equal to unity $[\mu(x)_{\tilde{A}} = 1]$. Support of membership function is the region having a membership greater than zero $[\mu(x)_{\tilde{A}} > 0]$. Boundary of membership function is the region having membership more than zero but less than unity $[0 < \mu(x)_{\tilde{A}} < 1]$. This is more clearly explained in Figure 2-3 (Ross 2009).
The fuzzy set having at least one element as unity membership function is said to be a normal fuzzy set and that element is termed as prototypical element. If the membership values are monotonically increasing, monotonically decreasing or monotonically increasing and then monotonically decreasing, the membership function is said to be convex fuzzy set (Ross 2009). A Triangular Fuzzy Number (TFN) is an example of convex normal fuzzy set. For the formation of TFN, minimum value, most-likely value and maximum value are mapped on the universe of discourse. The average operators can be used to find the most-likely value of a given factor. Apart from TFN, trapezoidal fuzzy numbers can also be used if the most likely values are two, as shown in Figure 2-3. In trapezoidal fuzzy number, the core of membership function will be having some value and there will be two prototypical elements. Only normal convex bounded fuzzy set are considered as fuzzy numbers (Sadiq and Rodriguez 2004).

2.5.3.1 Development of Membership Functions

The development of membership function is important because all information of fuzzy set is embodied in the membership function. Despite of the restrictions of defining the shape of fuzzy set, infinite number of ways are present to characterize fuzziness and represent the fuzzy set in graphical ways. The shape of membership function is dependent on type of variables and type of problem (Dyck et al. 2014). To assign membership values or functions to fuzzy variables, most common methods are intuition, inference, rank ordering, neural networks, genetic algorithms and inductive reasoning. The important characteristic of membership functions to use in fuzzy operations is their ability to overlap. This over-lapping induces the fuzziness in the system. Instead of precise shapes of curves; the placement of curve on universe of discourse, the number of curves and overlapping characteristics are more important to form the fuzzy set (Ross 2009). Intuition is the capacity to derive membership function based on the human understanding and knowledge. Based on intuition, the number of curves for membership functions is formed based on seven-point scale being used by psychologists for a long time. Based on the experiments on the capacity of people to transmit information, it was found that there are some limitations on the amount of information that human retrieve, process and remember. Based on those limitations, an average number of human capacity for processing information is seven, plus or minus two (Miller 1956). It is also recommended to have categories less than seven for better understanding (Karwowski and Mital 1986). The number of membership functions is also called granularity.
The granularity can be defined by experts or industrial persons and can range from minimum of three to maximum of eleven qualitative levels (Khan and Sadiq 2005). A typical membership function is shown above in Figure 2-3.

2.5.3.2 Cardinality of Fuzzy Relations
Cardinality of a fuzzy set is the summation of the intersection of input data with the membership functions already defined on the universe of discourse. Cardinality of a fuzzy set is important to establish the normality of fuzzy set, fuzzy inference rules and fuzzy quantified rules. Fuzzy cardinality can be described in two concepts. One gives the output as a fuzzy set while other gives output as an ordinary integer (Ralescu 1995). For a random factor developed in Table 2-5, cardinality is calculated in Figure 2-4.

Table 2-5: TFN for a Random Indicator

<table>
<thead>
<tr>
<th>Factor</th>
<th>Minimum Value</th>
<th>Most-Likely value</th>
<th>Maximum Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>30</td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>Acceptable</td>
<td>40</td>
<td>50</td>
<td>60</td>
</tr>
<tr>
<td>Not-Acceptable</td>
<td>50</td>
<td>60</td>
<td>70</td>
</tr>
</tbody>
</table>

\[ Fuzzy \ Set = \{ \begin{align*}
& 0.75 \oplus 0.75 \oplus 0.25 \\
& \text{Excellent} \oplus \text{Acceptable} \oplus \text{Not-Acceptable}
\end{align*}\]

\[ Cardinality = 0.75 + 0.75 + 0.25 = 1.75 \]

\[ Normalized \ Fuzzy \ Set = \{ \begin{align*}
& 0.428 \oplus 0.428 \oplus 0.144 \\
& \text{Excellent} \oplus \text{Acceptable} \oplus \text{Not-Acceptable}
\end{align*}\]

Figure 2-4: Calculating Membership, Cardinality, and Normalized Fuzzy Sets of Fuzzy Input
Like the crisp logic rules and transformations (e.g. differentiation, integration, matrices, Laplace transformation, etc.), fuzzy set theory also has its own rules and evaluation techniques such as Fuzzy Composite Programming (FCP), Fuzzy Rule-based Systems (FRBS), and Fuzzy Synthetic Evaluation (FSE). In this study, FSE is used and a brief overview is given below.

### 2.5.4 Fuzzy Synthetic Evaluation

The basic concept of fuzzy techniques is the interval analysis which addresses uncertain and imprecise information (Sadiq et al. 2004). The word synthetic in FSE represents that FSE is a process of synthesizing several individual component inputs of evaluation into a single aggregate output (Ross 2009). Output is express as the weighted average of input values. FSE is an evaluation technique to group raw data into predetermined quality criteria, called membership functions, which are fuzzy in nature (Dahiya et al. 2007). FSE uses fuzzy mathematics to transmute imprecise information (Kuo and Chen 2006). The main steps of FSE are (Tesfamariam and Saatcioglu 2008):

1. Framework generation
2. Fuzzification
3. Aggregation
4. Defuzzification

#### 2.5.4.1 Framework Generation

The analysis is based on the framework which is generated in a hierarchical manner, just like other MCDM techniques, in which system indicators are arranged such that output function is at top level and basic factors or inputs are at the most bottom level. In-between levels are generated by interpolating the level of importance of groups and sub-groups. At most bottom level, indicators are defined so that further integration is not possible (Sadiq et al. 2004). These are based on primary and secondary sources which consist of published and unpublished articles (Khatri et al. 2011). The factors are arranged in a way that indicators affecting a typical system are grouped under one main category. As already mentioned, the values of the bottom level factors could be crisp or fuzzy. Furthermore, factors could be arranged regardless of their units. For example, curb height (mm), pathway slope (%age), number of boarding and alighting (unit-less), and time schedule (sec) can all be grouped under design of transit stop. While forming
fuzzy set during fuzzification, the membership values will be used for further calculations. Fuzzy synthetic evaluation can deal with all these kind of multi-unit data (Sadiq et al. 2004).

2.5.4.2 Fuzzification
Fuzzification involves the conversion of crisp quantity into a fuzzy quantity. It is a fact that many quantities which seems crisp to us are not crisp at all and contain a certain amount of uncertainty in them (Ross 2009). For example, consider the number of transit users at a transit stop. It seems that there are a crisp number of transit users waiting for the transit at a given stop but how precisely can we predict that crisp number? In real life, the number of transit users is uncertain to predict and it inculcates an uncertainty in the design of transit stop facilities which are designed based on the amount of transit user. Because this uncertainty is created based on imprecise, ambiguous and vague human understanding, therefore, this variable is fuzzy in nature and can be represented in the form of membership functions (Ross 2009). Fuzzification involves the benchmarking of factors on the universe of discourse by formation of membership functions (Khan and Sadiq 2005). The method of fuzzification depends on the type of input data (Khatri et al. 2011). Input into a fuzzy system may be crisp or fuzzy (Ross 2009). Fuzzy input has been discussed in Figure 2-4. A crisp input to any fuzzy system is handled in same way as fuzzy input as shown in Figure 2-5. In most cases, but not necessary, the cardinality of crisp input is equal to unity. This will depend on the shape of membership function. If the membership functions are formed such that the most likely value of one function (say excellent in Figure 2-5) is same as the least likely value of next function (say acceptable in Figure 2-5), then the cardinality of crisp input would be unity. The fuzzy set is formed by mapping each input variable on the pre-defined membership functions and the membership value of every function is determined corresponding to the intersection point of input variable with the functions (Khan and Sadiq 2005). If the input value has an intersection with the membership functions at more than single point, the fuzzy maximum operation is considered for further calculations (Sadiq et al. 2004).
Normalized Fuzzy Set = \[ \left\{ \frac{0}{\text{Excellent}} \oplus \frac{0.25}{\text{Acceptable}} \oplus \frac{0.75}{\text{Not Acceptable}} \right\} \]

Cardinality = 0 + 0.25 + 0.75 = 1.00

2.5.4.3 Aggregation

In fuzzy synthetic evaluation, indicators are assigned relative weights based on their importance. The relative importance of these indicators is subjective in nature and these subjective weightings come from the field experts (Khatri et al. 2011). The main idea of aggregation is synthesizing the lower level (local) weights into upper level (global) weights (Kuo et al. 2002). The weights of lower level are transferred to upper level by performing aggregation operation by matrix operation on weight vector and evaluation matrix of a particular level (Khatri et al. 2011). Suppose 2 factors (\( \tilde{T} \) & \( \tilde{B} \)) are arranged under \( \tilde{U} \), as shown in Figure 2-6. Relative weights of factors are denoted by \( W_{\tilde{T}} \) and \( W_{\tilde{B}} \). Fuzzy set of factors are (say)
Then the fuzzy set of \( \tilde{U} \) is given in Equation 2-12.

\[
\tilde{U} = (\tilde{u}_1, \tilde{u}_2, \tilde{u}_3, \tilde{u}_4, \tilde{u}_5)
\]

There are several methods to compute the relative weights which include the conventional methods and multi-criteria decision-making (MCDM) techniques. Conventional methods include factor rating system and simple additive weight. Most widely applied MCDM technique is the Analytical Hierarchical Process (AHP). Based on the axioms of AHP, there are some limitations which lead to several modified versions of AHP. Next section, Section 2.6, deals with the detailed overview of all these techniques.

### 2.5.4.4 Defuzzification

If is often difficult to make decisions on some ambiguous information. A crisp mathematical integer makes it easy to decide the best optimum result. Defuzzification is opposite to fuzzification and involves the conversion of fuzzy input to crisp output. Timothy J. Ross (2009), in his book, “Fuzzy Logic with Engineering Applications” has listed seven most common methods for Defuzzification. These includes maximum membership principle, centroid method, weighted average method, mean maximum membership, center of sums, center of largest area and first (or last) of maxima. To choose the best method among all is dependent on context of problem being solved. However, there are 5 criterions which are to be considered in deciding the method to be applied. These include continuity, dis-ambiguity, plausibility, computational simplicity and weighted method (Hellendoorn and Thomas 1993). In this study, the scoring method of defuzzification, as adopted by Sadiq and Rodriguez (2004), Khan and Sadiq (2005), and Sadiq et al. (2004), is applied. Scoring method is mathematically shown in Equation 2-13.
\[
\text{Defuzzification} = \sum_{i=1}^{n} \delta_i \mu_i
\]

Equation (2-12)

Where;
- \( \delta \) = Relative weight coefficient
- \( \mu \) = Membership value
- \( n \) = Granularity

Granularity is defined as the number of membership functions plotted on the universe of discourse. Scoring method of defuzzification gives a crisp number by assigning weights to the membership values of fuzzy sets (Sadiq and Rodriguez 2004)(Khan and Sadiq 2005). The relative weight coefficients of membership function are of great importance and must be decided based on expert’s opinion. If larger values are assigned to better membership function, it shows the optimistic nature of decision maker. If higher values are assigned to lower membership function, it shows the pessimistic nature of decision maker. Equal weights to all functions shows that the decision maker has a compromising attitude (Sadiq et al. 2004) (Khan and Sadiq 2005).

2.6 MCDM Techniques for Aggregation

Conventional approaches mainly depend on the simple and easy-to-use techniques like regression analysis, analog approach, expert judgment, checklist method, breakeven analysis, center-of-gravity method, transportation model and factor rating system (Chou et al. 2008)(Kuo et al. 2002). In regression analysis, main factors effecting final decision and their degree of influence on final decision are determined. Analog approach determines the limits of final decision and then analyzes different options to predict the best one (Applebaum 1968). In conventional analysis, the individual ability can also influence the final decision (Kuo et al. 2002). Two methods among conventional methods have gained more importance, Factor Rating System (FRS) and Simple Additive Weight (SAW). FRS is also called multi-factor rating system (Chou et al. 2008). SAW is the most frequently used conventional method (Hwang and Yoon 2012) (Chang and Yeh 2001) (Virvou and Kabassi 2004). SAW is based on two simple steps (Hwang and Yoon 2012) (Virvou and Kabassi 2004). First step is to determine the relative weights of each criteria and second step is to normalize them so that their sum would be equal to unity. The conventional approaches of decision-making only help to provide a systematic approach based on locally available factors and do not consider their effect globally (Kuo et al. 2002).
Database management system was developed which store the information from different sources and then use that information for further calculations (Junthirapanich 1992). This type of decision support tool can only be used by experts in a sequential manner (Kuo et al. 2002). To overcome this limitation, neuro-computing group decision support system was introduced but it determines only the top limit of final decision and do not provide overall ranking (Chi et al. 1996).

Comparison of several MCDM techniques was first studied by taxonomy of MCDM methods (MacCrimmon 1973). A simulation of eight Multi-Criteria Decision-Making (MCDM) methods have shown that simple evaluation techniques are often superior than others (Chang and Yeh 2001) (Zanakis et al. 1998). These eight MCDM methods involve SAW, multiplicative exponential weighting (MEW), technique for order preference by similarity to the ideal solution (TOPSIS), elimination and (et) choice translating reality (ELECTRE) and four modified versions of analytical hierarchical process (AHP). AHP is a stand-alone methodology which is used to handle complex problems related to site selection (Min 1994) (Yang and Lee 1997) (Tabari et al. 2008). Besides handling multiple criteria problems easily in a hierarchical manner, it can handle both qualitative and quantitative data (Badri 1999) (Kahraman et al. 2004). For selection between alternatives, AHP was designed by Thomas L. Saaty (1980) which is a decision synthesis approach. AHP is a framework process which is used for alternative selection based on intuition, rational, irrational, multi-criteria and multi-actor decisions (Saaty 1986).

2.6.1 Analytical Hierarchical Process

Analytical Hierarchical Process (AHP) is the most extensively used multi-criteria decision-making tool due to its easy-to-use ability, practicality and extraction of multiple expert opinion and systemization of complex problems (Shiau et al. 2002). AHP is widely applied in management related areas of construction which include technology evaluation, material assessment, selection of contractor, proposal and project evaluation selection, equipment identification and asset management model credibility. Despite of all other methods, AHP can deal with intangible and tangible criterions related to engineering, management and economy (S. Lee 2014) (Hastak 1998).
AHP works under two major stages. At first stage, a hierarchical structure is formed which contains the levels and sub-levels of criterions and factors, respectively. This hierarchical level is formed by knowledge and experience of problem being solved. After assigning hierarchical structure, the evaluation of each level is carried out to compute the priority weights of every factor at each level. The evaluation is done by pair-wise comparison relative to each other (S. Lee 2014).

AHP is based on the principles of decomposition, comparative judgments, and synthesis of priorities. Principle of decomposition is the formation of hierarchical level keeping goal at top level, criteria at middle level and alternatives at lower level. There is no limit for this hierarchical level and can be formed in relation to the complexity of problem. Then bottom-to-top rule is applied and alternatives are evaluated followed by criterions. Comparative judgment is the formation of decision matrix based on the input and pair wise comparison. Synthesis of priorities mainly deals with the multiplication of local priorities with global priorities (Saaty 1986). A brief description of its steps is given below.

2.6.1.1 Establishment of Hierarchical Levels

The main objective of formation of hierarchical levels is to include every factor in decision-making process, to establish the interdependencies between them (Hastak 1998), and to decompose the complexity into further divisions (Shapira and Goldenberg 2005). Levels are arranged from top-to-bottom arrangement. The primary objective of problem lies on top level of hierarchy, on second level from top, the main factors are listed. At lowest level, which are also called indicators, are the basic elements which need to be evaluated (Shapira and Goldenberg 2005). The levels of hierarchy are not constant and increase with the increase in complexity of problem (Hastak 1998). These levels are commonly known as goal, criteria, sub-criteria and alternatives (Bhushan and Rai 2007). The hierarchy formed is synthesized according to decision makers preference based on decision matrix computation and pairwise comparison of all criterions. In general, for “n” number of factors, the number of pair wise comparison can be calculated by Equation 2-14 (Hotman 2005).
No of pair wise comparison = n x \( \frac{n - 1}{2} \)  

Equation (2-13)

2.6.1.2 Pair Wise Comparison Matrix

A decision matrix \( A = a_{ij} \) \((i, j = 1, \ldots, n)\) is formed based on experts’ opinion and pair rise comparison between \(a_i\) and \(a_j\). The decision matrix is established based on pre-defined scale of 1 to 9, as suggested by Thomas L. Saaty. The scale is given in Table 2-6.

Table 2-6: Saaty’s Scale of Relative Importance

(Saaty 1986)

<table>
<thead>
<tr>
<th>Scale</th>
<th>Definition</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equal importance</td>
<td>Two activities contribute equally to the objective.</td>
</tr>
<tr>
<td>3</td>
<td>Moderate importance of one over another</td>
<td>Experience and judgment slightly favor one activity over another.</td>
</tr>
<tr>
<td>5</td>
<td>Essential or strong importance</td>
<td>Experience and judgment strongly favor one activity over another.</td>
</tr>
<tr>
<td>7</td>
<td>Demonstrated importance</td>
<td>An activity is strongly favored and its dominance is demonstrated in practice.</td>
</tr>
<tr>
<td>9</td>
<td>Extreme importance</td>
<td>The evidence favoring one activity over another is of the highest possible order of affirmation.</td>
</tr>
<tr>
<td>2,4,6,8</td>
<td>Intermediate values</td>
<td>When compromise is needed.</td>
</tr>
<tr>
<td><strong>Reciprocal</strong></td>
<td></td>
<td>Ratios arising from the scale</td>
</tr>
<tr>
<td><strong>Rationales</strong></td>
<td></td>
<td>If consistency were to be forced by obtaining n numerical values to span the matrix</td>
</tr>
</tbody>
</table>

The two important characteristics of this decision matrix is that all the elements are positive and for all, \( a_{ji} = 1/a_{ij} \). For each level, a separate decision matrix has to be formed and comparison should be made (Shapira and Goldenberg 2005). While making decision matrix, the importance of factor over others and intensity of that importance is determined (Shapira and Goldenberg 2005). Verbal intensity is translated into numerical intensity by using Saaty intensity scale. In decision matrix \( A \), for all, \( a_{ij} = 1 \) where \( i = j \).

The expert opinion can be taken from more than 1 expert. In some cases, 15 to 20 experts can be interviewed for their input (Kuo et al. 2002). So in order to aggregate the input from different
experts, Geometric Method of Buckley can be used (Buckley 1985a) (Buckley 1985b) which is
given in Equation 2-15.

\[ b_{ij} = \left( \prod_{i=1}^{n} a_{ijk} \right)^{1/n} \]  

Equation (2-14)

Where:
- \( a \) = element of \( k \)-th decision maker matrix
- \( b \) = element of aggregated decision matrix
- \( n \) = total number of inputs from decision makers

### 2.6.1.3 Relative – Weight Calculation

According to Saaty (1986) axiom, the eigenvector of decision matrix is the priority vector that
shows relative weight of a particular level. For calculation of eigenvector, several methods are
available, but important are Geometric Mean Method (GMM) (Saaty 1986) (Yoon and Hwang
1995) (Aczel and Saaty 1983) and Average of Normalized Column method (ANC) (Shapira and
Goldenberg 2005). GMM is recommended for synthesis of a diverse judgment which is given in
Equation 2-16.

\[ w_i = C \cdot \left( \sum_{k=1}^{n} a_{ik} \right)^{1/n} \quad i = 1, \ldots, n \]  

Equation (2-15)

Where
- \( C \) = Normalization factor

### 2.6.1.4 Aggregation of Relative Weights

Aggregation is performed after the calculation of eigenvector. The weights obtained for lowest
level of hierarchy is utilized to form the respective alternative choice of level just above that. The
new vector formed is a global vector which is formed by combination of local vectors (Shapira
and Goldenberg 2005). It is more suitable for a multi-hierarchical computation.
2.6.1.5 Consistency Ratio

Due to subjective judgment and intuition in AHP, an absolute consistency is not possible (Shapira and Goldenberg 2005). There is a specific limit for inconsistency in the decision matrix. Based on axioms of AHP, the inconsistency of less than 10% is desirable (Shiau et al. 2002) (Martin and Lafond 1988). This is calculated by Consistency Ratio (CR) which is a ratio of Consistency Index (CI) to Random Consistency Index (RCI) (Hastak 1998). CI can be computed as given in Equation 2-17 (Hastak 1998) (Saaty 2008) (Scott 2002) (Han W.J. and W.D. 1998) (Malczewski 1999).

\[
CI = \frac{\gamma_{max} - n}{n - 1}
\]

Equation (2-16)

Where;
- \(\gamma_{max}\) = maximum eigenvector value for matrix under consideration
- \(n\) = number of alternatives involved in particular matrix

RCI is the average of large number of reciprocal matrix of same order with random entries (Hastak 1998). The RCI is obtained from Table 2-7 given below (Kong and Liu 2005) (Kordi 2008).

<table>
<thead>
<tr>
<th>Matrix Size</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCI</td>
<td>0</td>
<td>0</td>
<td>0.58</td>
<td>0.90</td>
<td>1.12</td>
<td>1.24</td>
<td>1.32</td>
</tr>
</tbody>
</table>

In practical case where input data is coming from different sources and from different experience persons, the consistency ratio may be deviated due to exhausted pair wise comparison. So, in this case, a generous consistency limit can be applied (S. Lee 2014).

2.6.2 Simple Additive Weight

Simple Additive Weighting (SAW) is most commonly used Multi-Criteria Decision-Making tool. It is easy to use and is also called weighted linear combination or scoring method. After establishment of hierarchical structure, first a pair wise comparison matrix of order \((n \times n)\) is formed based on AHP scale as described above. Then priority vector (PV) is formed by row average (Choo and Wedley 2004) as shown in Equation 2-18.
\[ PV_i = \frac{1}{n} \sum_{j=1}^{n} a_{ij} \]  
\text{Equation (2-17)}

Where;
- \( n \) = number of alternatives

Then weighted sum average (WSA) is established by multiplying pair wise comparison matrix with PV (Afshari et al. 2010) as given in Equation 2-19.

\[ WSA_i = a_{ij} \times b_{i'j'} \]  
\text{Equation (2-18)}

Where;
- \( a_{ij} \) = element of matrix on \( i_{th} \)-row and \( j_{th} \) column
- \( b_{ij} \) = element of priority vector on \( i_{th} \) row and \( j_{th} \) column

### 2.6.3 Limitations of AHP

The extensive use and demand popularity of AHP reveal some limitations. In counter to that, some researchers believed that the limitations of AHP arise due to lack of theoretical knowledge of AHP and reluctance to move away from conventional methods (Harkerp and Vargas 1987). However, others stated that AHP is a flawed process because it only gives an arbitrary ranking and weights. AHP can be properly use by merging AHP with multi-factor utility theory (Dyer 1990). Some of the limitations of AHP include:

- **Scale** (Belton 1986) (Dyer 1990): The scale of 1 to 9 as prescribed by Thomas L. Saaty (1980) adds inconsistency into the weight system. If the scale is changed as (say) 1 to 5 instead of 1 to 9, then the weights of alternatives also change. But Belton and Goodwin (1996) argued that this short coming can be removed by complete knowledge of scale and AHP.

- **Consistency ratio**: The AHP proposed by Thomas L. Saaty (1980) can tolerate a consistency of less than 10%. However, in practical life, the consistency may go beyond that limit. Therefore, S. Lee (2014) argued that when the input for paired comparison is coming from the expert and experienced persons, then somewhat generous consistency
limit can be applied to solve the problem. In other words, sometimes the consistency ratio can be neglected to achieve the target.

- **Synthesizing vast judgment** (S. Lee 2014): In almost every problem, the input is taken from a number of experts to have a diverse opinion. AHP cannot synthesize a diverse data collected and therefore some basic mathematical concepts are used like geometric mean, arithmetic mean or mean including weights. In general, geometric mean is recommended to synthesize a diverse judgment (Saaty 1986) (Aczel and Saaty 1983).

- **Lack of uncertainty** (Srichetta and Thurachon 2012): The main drawback of AHP is that it cannot answer the uncertainty in decision-making input. Experts are often uncertain to pick a crisp number from traditional AHP scale of 1 to 9. To cater this drawback, fuzzy-AHP was derived from conventional AHP by blending traditional AHP with fuzzy set theory proposed by Zadeh (L.A. Zadeh 1965)(Soroor et al. 2012)(Petkovic et al. 2012).

- **Eigenvector** (Dyer 1990): The formation of eigenvector to tackle the inconsistent response also doesn’t sound good. However, Barzilai et al. (1987) proposed that geometric mean method can be more suitable to deal with the inconsistency.

- **Same Alternatives** (Harkerp and Vargas 1987): If we rank (say) 4 alternatives and assign them weights, then the addition of another alternative, same or slightly different, not only disturb the previous ranking but also it did not rank new alternative close to its copied original alternative. Although, they should be rank same or close to each other. Not to rank “slightly different” alternatives close is also a limitation of AHP. Therefore, when the concept of hierarchical composition is assumed, it yields an arbitrary result (Dyer 1990). However, in the basic axiom of AHP proposed by Saaty (1986), it is mentioned that no two alternative can be identically same (Harkerp and Vargas 1987).

- **Independence of alternatives** (Kuo et al. 2010): One of the limitations of AHP is that it treats the criteria and alternatives independently. In order to solve this limitation, Saaty introduced Analytical Network Process (ANN). ANN allows the dependence of alternatives over criteria and vice versa (Satty 2001).

- **Exhausted pair-wise comparison** (Hotman 2005): If the alternatives are more in number, the AHP is a very exhausted pair-wise comparison method and needs a lot of time. From practical point of view, it is not feasible. This problem may be solved by
Hierarchical decomposition (Scott 2002), duality approach (Triantaphyllou 1999) or Base Reference AHP (BR-AHP) (Hotman 2005).

Based on the limitations of AHP, some modified versions of AHP were developed which are discussed below.

2.6.4 Base Reference AHP

One of the limitations of AHP is the exhausted pair wise comparison from practical approach (Hotman 2005). Also, the pair wise comparison denies the need of any baseline or standard to establish the decision (Dyer 1990). All these problems were addressed by Hotman (2005) and he proposed a modified version of AHP and called it Base Reference AHP (BR – AHP). In BR – AHP, all alternatives are compared to a standard or known alternative to establish the decision. Compared to Saaty’s AHP which needs \( n(n-1)/2 \) comparison, BR – AHP only needs \( (n-1) \) comparison. For 100 alternatives, (say) BR – AHP reduces the comparison matrix from 4950 to 99 (Hotman 2005).

For BR – AHP, one alternative is considered as benchmark or base line, Hotman (2005) refer to it as Base Reference. Base Reference alternative is compared with all other alternatives and numerical priorities are provided through experts. All other elements of decision matrix are calculated by Equation 2-20.

\[
\begin{align*}
    b_{ij} = \begin{cases} 
    1 & i = j \\
    \min \left\{ 9, \frac{b_{kj}}{b_{ki}} \right\} \frac{b_{kj}}{b_{ki}} > 1 & i \neq j \\
    \max \left\{ \frac{1}{9}, \frac{b_{kj}}{b_{ki}} \right\} \frac{b_{kj}}{b_{ki}} < 1 & i \neq j 
    \end{cases}
\end{align*}
\]

Equation (2-19)

Where;

- \( b_{ij} \) = element of decision matrix ( > 0 )

Scale used in BR – AHP is same as used in AHP i.e. a 9-point scale which range from 1/9 to 9.0. To ensure consistency, higher values than 9 are eliminated by use of minimum operator and less values from 1/9 are also eliminated by using maximum operator (Hotman 2005).
2.6.5 Average Normalized Column AHP

For calculation of eigenvector and weights of alternative, as explain earlier, geometric mean method and Average Normalized Column (ANC) method are normally used (Shapira and Goldenberg 2005). In order to analyze and select best method of MCDM for our problem, ANC method was studied and compared with other methods (Shapira and Goldenberg 2005)(Hastak 1998). According to ANC, the eigenvector is calculated first by normalizing the elements of decision matrix and then taking row average of modified decision matrix by Equation 2-21.

\[ w_i = \text{Average} \left( \frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}} \right) \]

Equation (2-20)

Where;
- \( w_i \) = Weight of \( i \)-th criteria
- \( n \) = Number of Criterions
- \( a_{ij} \) = Element of matrix at \( i \)-th row and \( j \)-th column

2.6.6 Ideal Mode AHP

One of the limitations of AHP proposed by Thomas L. Saaty in 1971 was rank reversal. With the addition or deletion of a new alternative, the ranking of all system is disturbed (Shapira and Goldenberg 2005) (Dyer 1990) (S. Lee 2014) (Belton and Gear 1983). To cater with this problem, the use of absolute measurements was considered instead of relative measurement (S. Lee 2014) (Belton and Gear 1983) (Triantaphyllou and Sanchez 1997). In relative measurement, the sum of weights of alternatives is unity but in absolute measurement, relative value of each eigenvector is divided by the maximum value to obtain priority vector. Saaty accepted this modification in weight calculation and called it an Ideal Mode AHP (Saaty 1994).

2.6.7 Fuzzy AHP

As explained earlier, one of the limitations of AHP is its inability to handle uncertainty and vagueness in data. The experts are often uncertain about the crisp scale of AHP developed by Thomas L. Saaty in 1971 (Srichetta and Thurachon 2012). Fuzzy set theory proposed by Lofti A. Zadeh (1965) has the ability to handle imprecise information originated due to human’s judgment (Ayhan 2013)(Khatri et al. 2011)(Sadiq and Rodriguez 2004)(Rajani et al. 2006).
Therefore, there was a need of a process which can handle these uncertainties and give a crisp output in the form of priority vector, as in AHP. Therefore, fuzzy – AHP (F-AHP) was proposed which is a mixture of traditional AHP and Zadeh’s fuzzy set theory (Ayhan 2013)(Petkovic et al. 2012).

F-AHP works by using a membership function and linguistic variables (Soroor et al. 2012) (Van et al. 1983) (Buckley 1985a) (Chang 1996). The main advantage of Fuzzy AHP is that besides solving typical management problems as with AHP, it can deal with risk management more affordably (Mostafavi and Karamouz 2010). Triangular fuzzy numbers [TFN] are a set of 3 real numbers that defines the boundary of a fuzzy set. They are denoted as \( l, m, u \) such that \( l \leq m \leq n \) (Srichetta and Thurachon 2012). For two triangular fuzzy sets, say \( \tilde{A}_1 (l_1, m_1, n_1) \) and \( \tilde{A}_2 (l_2, m_2, n_2) \), the basic operators are given in Equation 2-22 (Srichetta and Thurachon 2012) (Zhang 2010)(Sangwook Lee 2014):

\[
\begin{align*}
(a) \text{ Addition:} & \quad \tilde{A}_1 + \tilde{A}_2 = (l_1+l_2, m_1+m_2, n_1+n_2) \\
(b) \text{ Multiplication:} & \quad \tilde{A}_1 \times \tilde{A}_2 = (l_1l_2, m_1m_2, n_1n_2) \\
(c) \text{ Inverse:} & \quad \frac{1}{\tilde{A}_1} = \left( \frac{1}{n_1}, \frac{1}{m_1}, \frac{1}{l_1} \right) \\
(d) \text{ Scalar Multiplication:} & \quad \gamma \cdot \tilde{A}_1 = (\gamma l_1, \gamma m_1, \gamma n_1)
\end{align*}
\]

The inverse property is used to establish decision matrix in F-AHP. The membership function of TFN resemble with fuzzy set theory of Lofti A. Zadeh (1965). The membership function \( \mu_M(x) \) of TFN over the universe of discourse can be mapped as shown in Equation 2-23 (Srichetta and Thurachon 2012)(Sangwook Lee 2014) (Tabari et al. 2008)

\[
\mu_M(x) = \begin{cases} 
0 & x \leq l \\
\frac{(x-\ell)}{(m-\ell)} & l \leq x \leq m \\
\frac{(n-x)}{(n-m)} & m \leq x \leq n \\
0 & \text{otherwise}
\end{cases}
\]

\[\text{Equation (2-22)}\]

Saaty’s AHP was first extended by De Grann (1980) and Demirel et al. (2008) but Chang extension of fuzzy AHP is more commonly used (Zhang 2010). The main steps of CE-FAHP are listed below.

53
2.6.7.1 The TFNs Scale

Scale for F-AHP is composed of TFNs. Three types of fundamental scales used in F-AHP are given in Table 2-8 (a), (b), and (c).

**Table 2-8: Fuzzy Fundamental Scale**

(a) Proposed by Yazdani and Yakhchali (2012) and Zeki Ayag (2005)

<table>
<thead>
<tr>
<th>Linguistic Term</th>
<th>Fuzzy Number</th>
<th>Triangular Fuzzy Number</th>
<th>Triangular fuzzy reciprocal scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equal importance</td>
<td>~1</td>
<td>(1, 1,1)</td>
<td>(1, 1,1)</td>
</tr>
<tr>
<td>Intermediate</td>
<td>~2</td>
<td>(1, 2,3)</td>
<td>(1/3, 1/2, 1)</td>
</tr>
<tr>
<td>Moderate importance</td>
<td>~3</td>
<td>(2, 3,4)</td>
<td>(1/4, 1/3, 1/2)</td>
</tr>
<tr>
<td>Intermediate</td>
<td>~4</td>
<td>(3, 4,5)</td>
<td>(1/5, 1/4, 1/3)</td>
</tr>
<tr>
<td>Strong importance</td>
<td>~5</td>
<td>(4, 5,6)</td>
<td>(1/6, 1/5, 1/4)</td>
</tr>
<tr>
<td>Intermediate</td>
<td>~6</td>
<td>(5, 6,7)</td>
<td>(1/7, 1/6, 1/5)</td>
</tr>
<tr>
<td>Very strong importance</td>
<td>~7</td>
<td>(6, 7,8)</td>
<td>(1/8, 1/7, 1/6)</td>
</tr>
<tr>
<td>Intermediate</td>
<td>~8</td>
<td>(7, 8,9)</td>
<td>(1/9, 1/8, 1/7)</td>
</tr>
<tr>
<td>Extreme importance</td>
<td>~9</td>
<td>(8, 9,10)</td>
<td>(1/10, 1/9, 1/8)</td>
</tr>
</tbody>
</table>

(b) Proposed by Khazaeni et al. (2012)

<table>
<thead>
<tr>
<th>Linguistic Term</th>
<th>Fuzzy Number</th>
<th>Triangular Fuzzy Number</th>
<th>Triangular fuzzy reciprocal scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equal or not important</td>
<td>~1</td>
<td>(1, 1,1)</td>
<td>(1, 1,1)</td>
</tr>
<tr>
<td>Weak important</td>
<td>~3</td>
<td>(1, 3,5)</td>
<td>(1/5, 1/3, 1)</td>
</tr>
<tr>
<td>Moderate important</td>
<td>~5</td>
<td>(3, 5,7)</td>
<td>(1/7, 1/5, 1/3)</td>
</tr>
<tr>
<td>Strong important</td>
<td>~7</td>
<td>(5, 7,9)</td>
<td>(1/9, 1/7, 1/5)</td>
</tr>
<tr>
<td>Extreme important</td>
<td>~9</td>
<td>(7,9,9)</td>
<td>(1/9, 1/9, 1/7)</td>
</tr>
</tbody>
</table>

(c) Proposed by Srichetta and Thurachon (2012)

<table>
<thead>
<tr>
<th>Linguistic Scale</th>
<th>Triangular Fuzzy Number</th>
<th>Triangular fuzzy reciprocal scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equally important</td>
<td>(1, 1,1)</td>
<td>(1, 1,1)</td>
</tr>
<tr>
<td>Weakly more important</td>
<td>(2/3, 1, 3/2)</td>
<td>(2/3, 1, 3/2)</td>
</tr>
<tr>
<td>Strong more important</td>
<td>(3/2, 2, 5/2)</td>
<td>(2/5, 1/2, 2/3)</td>
</tr>
<tr>
<td>Very strong more important</td>
<td>(5/2, 3, 7/2)</td>
<td>(2/7, 1/3, 2/5)</td>
</tr>
<tr>
<td>Absolutely more important</td>
<td>(7/2, 4, 9/2)</td>
<td>(2/9, 1/4, 2/7)</td>
</tr>
</tbody>
</table>
2.6.7.2 Decision Matrix
The decision matrix of F-AHP and AHP are alike with the difference of scale and TFNs. In AHP, crisp numbers are used while in F-AHP, fuzzy TFNs are used. If \( \tilde{a}_{ij} (l_1, m_1, n_1) \) is an element of decision matrix \( \tilde{A} \), then it’s reciprocal i.e. \( \tilde{a}_{ji} = 1/\tilde{a}_{ij} = (1/n_1, 1/m_1, 1/l_1) \) (Srichetta and Thurachon 2012).

2.6.7.3 Aggregation
For decision matrix to be representative of all decision makers, aggregation is performed by Geometric Method of Buckley (GMB). GMB for fuzzy differ from conventional AHP in dealing with TFNs (say \( \tilde{a}_{ij} = l_{ij}, m_{ij}, n_{ij} \)) instead of crisp number and is given in Equation 2-24.

\[
\tilde{a}_{ij} = \left( \prod_{k=1}^{n} \tilde{a}_{ijk} \right)^{1/n}
\]

Equation (2-23)

Where:
- \( n = \) total number of inputs from decision makers

2.6.7.4 Fuzzy Synthetic Extent
Relative weights of fuzzy synthetic extent can be calculated by weight aggregation method (Yazdani and Yakhchali 2012) or fuzzy arithmetic operations (Chang 1996)(Khazaeni et al. 2012).

Weight aggregation model (Yazdani and Yakhchali 2012) is given in Equation 2-25.

\[
\tilde{w}_{ij} = (L_{w_{ij}}, M_{w_{ij}}, N_{w_{ij}})
\]

Equation (2-24)

Where:
- \( L_{w_{ij}} = \min_t \{L_{w_{ijt}}\} \)
- \( M_{w_{ij}} = \frac{1}{T} \sum_{t=1}^{T} M_{w_{ijt}} \)
- \( N_{w_{ij}} = \max_t \{N_{w_{ijt}}\} \)


\[
\tilde{w}_{ij} = (L_{w_{ij}}, M_{w_{ij}}, N_{w_{ij}})
\]

Equation (2-25)
Where;

- \( L_{wij} = \frac{1}{T} \sum_{t=1}^{T} L_{wijd} \)
- \( M_{wij} = \frac{1}{T} \sum_{t=1}^{T} M_{wijd} \)
- \( N_{wij} = \frac{1}{T} \sum_{t=1}^{T} N_{wijd} \)

Fuzzy arithmetic operation is used to calculate fuzzy synthetic extent \((S_i)\) based on \(i\)-th criteria by using basic operators discussed above and by Equation 2-27 (Srichetta and Thurachon 2012) (Sangwook Lee 2014) (Yazdani and Yakhchali 2012) (Tabari et al. 2008)

\[
S_i = \sum_{j=1}^{m} \tilde{a}_{ij} \times (\sum_{l=1}^{n} \sum_{j=1}^{m} \tilde{a}_{ij})^{-1} 
\]

Equation (2-26)

Where:

- \( \sum_{j=1}^{m} \tilde{a}_{ij} = \sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j \)
- \( \sum_{l=1}^{n} \sum_{j=1}^{m} \tilde{a}_{ij} = (\sum_{l=1}^{n} l_i, \sum_{l=1}^{n} m_i, \sum_{l=1}^{n} n_i) \)

2.6.7.5 Fuzzy Priorities

To find the crisp relative weights, the degree of possibility between two fuzzy sets is calculated by method close to fuzzy set theory proposed by Lofti A. Zadeh (1965). The basic consideration of fuzzy synthetic extent is its ability to overlap. The degree of possibility that \(S_b \geq S_a\) is represented in Equation 2-28 (Tabari et al. 2008).

\[
V(S_b \geq S_a) = \begin{cases} 
1 & m_b \geq m_a \\
0 & l_a \geq n_b \\
\frac{l_a - n_b}{(m_b - n_b) - (m_a - l_a)} & \text{otherwise}
\end{cases} \quad \text{Equation (2-27)}
\]

Both values of \( V(S_b \geq S_a)\) and \( V(S_a \geq S_b)\) are calculated. The degree of possibility of an alternative can be computed by minimum operator (Dubois and Prade 1980). Let relative weight be presented by \(w'(S_i)\), then minimum operator is given in Equation 2-29.
\[ W'(S_i) = \min V(S_i \geq S_k) \]  
\text{Equation (2-28)}

where:

- \( k = 1, 2, \ldots, n \)

2.7 Summary

This chapter discussed the literature review about how ridership can be improved in relation to transit stop planning. Different researchers have tried to develop models but they did not include prioritization, superposition of factors, and uncertainties related to those factors. To deal with uncertainties, fuzzy set theory is presented which can deal with the ambiguous and vague information by aggregating different factors together by fuzzy synthetic evaluation. Different methods of aggregation are present but AHP has gained much more importance. The limitations of AHP led to some modifications which were also presented in this Chapter.
Chapter 3: Research Methodology

3.1 Outline
This chapter presents the research methodology adopted in this study. Section 3.2 provides an overview of research framework and different phases of research. Section 3.2.1 discusses the methodology adopted to develop hierarchical framework. Section 3.2.2 presents the approach used to collect data from experts about selected factors and Section 3.2.3 explains the approach adopted to develop TRANsit Stop inDEX tool, TRANSDEX. Section 3.3 concludes the chapter.

3.2 Research Framework
This research was conducted in three phases. In phase – 1, different factors that affect ridership were gathered. These factors were then shared with the experts in Phase – 2 to develop benchmarks and priority ranking of these factors. In phase – 3, expert feedback was used to develop TRANSDEX. Figure 3-1 shows these three phases.

3.2.1 Phase – 1: Hierarchical Framework Development
At this stage, past literature and transit agency manuals were consulted to find different ways for improving transit ridership. In general, two types of elements were defined which effect ridership. The first type of elements was internal to the transit system and the transit agency directly controls them. These were termed as “factors”. The second type of elements was external to the transit system and either the build environment control them or these are completely uncontrolled. These were termed as “indicators”. These factors and indicators were further categorized into two sub-types; transit stop-related factors/indicators and operational factors/indicators. Previous research has shown that waiting time at transit stop is perceived to be twice of its actual (Taylor et al. 2009). Therefore, in this study, only transit stop-related factors and indicators were studied. Transit stop factors and indicators were gathered through past literature and transit agency manuals to form the first version of a comprehensive hierarchical chart. The validity of these factors and indicators were measured through Delphi method. The first version of hierarchical chart was shared with the transit experts, in the form of a pilot survey. The feedback of the pilot survey was analyzed to revise the first version of hierarchical chart.
Hierarchical framework development

1. Define framework for transit stop planning
   - Define factors and indicators

2. Conduct expert opinion survey
   - Collect best practices w.r.t. city size
   - Collect ranking w.r.t. city size

3. Statistical hypothesis testing and MCDM
4. Develop guidelines for small and large cities

5. Applying fuzzy set theory to consider difference in expert-opinions and uncertainties related to transit stops

6. Guidelines include best practices and ranking of selected factors and indicator

7. Develop a decision support tool for transit stop planning

Figure 3-1: Research Framework

Criteria were defined about the removal or addition of factors and indicators based on the pilot survey feedback. Based on those criterions, some factors and indicators were removed from the chart while others were added. This second version of hierarchical chart was used to develop the full-fledged survey which was conducted among the transit experts across Canada. At the end of the survey, which was designed on second version of hierarchical chart, experts were requested...
for their feedback on the selected factors and indicators. This feedback was then used to test the survey content validity.

3.2.2 Phase – 2: Expert Opinion Survey

To collect the benchmarks and priority ranking of different factors and indicators based on city size, an expert opinion survey was designed in phase – 2 of this survey. This web-based survey was designed using the UBC Survey Tool and all the data collected from the survey was preserved on secure UBC server. This survey was designed in two major sections. First section collected the priority ranking of factors and indicators, whereas second section collected the best-practices of indicators. Survey was sent to transit experts using their email addresses which were obtained from Canadian Urban Transit Association (CUTA) membership directory. Survey content validity, construct validity, and response reliability tests were performed to make useful conclusions. The responses received from the experts were analyzed by statistical hypothesis testing to differentiate between benchmarks for small cities and large cities.

![Figure 3-2: Location of Large and Small Cities in Canada](image_url)
As shown in Table 1-1 in Section 1.2, CUTA classify Canadian cities into 5 classes based on their population. However, in this study, first two categories of CUTA division (i.e. having population more than 400,000) were merged together to form large cities and last three categories of CUTA division (i.e. having population less than 400,000) were merged together to form small cities. The location of small cities and large cities of Canada, as defined in this study, is shown in Figure 3-2. However, small and rural communities, which accounts for 5,156 numbers in total, are not shown in this figure.

3.2.3 Phase – 3: TRANSDEX

Using the factors and indicators defined in Phase – 1 and the expert feedback collected in phase – 2, an Excel-based decision-support tool, TRANSDEX, was formed using fuzzy synthetic evaluation, in phase – 3 of this study. Based on fuzzy synthetic evaluation, this model generates an index, which is based on factors selected in relation to transit stop planning. This customized Excel-based tool helps the decision makers to select factors based on the site condition and availability of data. Any factor or indicator can be removed to meet the stop location requirements. Not only the factors are customizable, but the benchmarks of membership functions and their priorities can also be changed as per the prevailing site condition. The Excel-based program is a tri-level framework, as shown in Figure 3-3 and is explained below.

3.2.3.1 Level 01: Defining Factors, Benchmark, Fuzziness, and Field Information

At this level, the user provides information about the factors and indicators that are applicable for index calculation based on specific site conditions and regional constraints. TRANSDEX allows the users to select the multiple factors, their benchmarks and degree of fuzziness that are representative of the proposed location, spacing and design of transit stop. The list of factors, their benchmarks and fuzziness provided by Excel-tool encompasses the complete criterion of transit stop planning but the site condition may only include some of them. This level is important because it incorporates the benchmarking and site condition into the system which is very crucial stage for the result generation. After benchmarking, field input is provided by the user.
Refine the customized list of factors/indicators provided, according to the need and availability of data and site condition

Based on output, redefine the system limiting values for a more feasible solution

Based on output diagrams, decide the feasibility of proposed location, spacing and design.

Meter-rating and factor rating charts are generated based on the all the input values and system limiting values.

For the factors/indicators selected, set priority ranking according to AHP. Ranking should be based on prevailing site conditions. If feasible, provided prioritization can be used

The field information of transit stop is entered in the tool. It consists of case specific information of that proposed location

Provide the ranges of membership functions of each indicator as per site data available. If feasible, provided data can also be used

Provide the %age by which the benchmarks of membership functions vary. If feasible, provided degree of fuzziness can also be used

TRANSDEX FLOWCHART

Figure 3-3: Tri-Level Street Transit Stop Index Framework
3.2.3.2 Level 02: Defining Priorities
At this stage, prioritization of factors are provided by the users which are based on the pair wise comparison of each level. Ranking should represent the real site consideration according to the prevailing circumstances. The priority calculation of pair wise comparisons is based on set path and methods, based on Analytical Hierarchical Process (AHP). At the end, results are generated based on all the inputs of variables, their benchmarking, fuzziness, priorities, and field data.

3.2.3.3 Level 03: Generating Results and Making Decision
Results of index-based tool are shown in the form of index and charts. After results generation, next step is to make a decision about the prospective transit stop. Transit stop allocation is composed of testing a series of scenarios and selecting that scenario which generate maximum index value. For this, the benchmarks and prioritization are kept constant and field information is changed with each scenario. The overall index gives the value which needs to be maximized and factor rating charts give the factors which need improvement. Based on the TRANSDEX values, the deficiencies can be addressed in a systematic way.

3.3 Summary
This chapter presented the three phases of this research. First, factors and indicators were gathered and validated through Delphi approach. Second, the benchmarks and prioritization of these factors and indicators were collected through a web-based expert opinion survey. Third, an Excel-based decision-support tool, TRANSDEX, was developed using the factors and indicators of phase – 1 and benchmarks and prioritization of phase – 2.
Chapter 4: Hierarchical Framework Development

4.1 Outline

This chapter discusses the first phase of this study, i.e. the hierarchical framework development. Section 4.2 defines the broad terms used in this study. Section 4.3 is about detailed explanation of different factors and indicators gathered and arranged to form the hierarchical chart. Section 4.4 is regarding the uncertainty categorization about transit stop planning. Section 4.5 concludes the chapter.

4.2 Factors vs. Indicators

In this research, two categories of elements that affect transit ridership were defined, namely, factors and indicators. Based on the literature and manuals, a hierarchical structure was formed comprising of four levels of factors (blue zone) and one level of indicators (orange zone), as shown in Figure 4-2.

A “factor” was defined as a transit stop quality that affects passengers’ perceptions of the service and could be used to evaluate the attractiveness of transit stops. Factors were controlled by the transit planner and could be arranged to form a hierarchical network and establish one-to-many relationships. Examples of factors included location of transit stop or provision of amenities (seats, shelter, etc.) at transit stop. An “indicator”, on the other hand, was defined as a measure that was used to define the required factor levels. For example, the number of transit users (indicator) required to offer a bench or seat (factor). Indicators were not directly controlled by the transit planner and were either dictated by the build environment (e.g. land use) or were completely uncontrolled (e.g. weather conditions). The recommended values of indicators vary greatly between transit manuals. For example, PTSG (1999) recommend minimum 50 transit users to provide seats/benches at a street transit stop, whereas, City of Folsom (2005) recommend minimum 5 transit users. Similarly, BC Transit (2010) recommend a maximum of 8% longitudinal sidewalk corridor slope for accessibility, whereas USDOT (2017) recommend maximum of 5%.
Factors were further classified into two sub-categories; based on removability. Removability was defined as whether a factor could be removed or added from the transit stop or it could only be improved (i.e. it is always there). Two categories of factors are:

- **Fixed Factors:** These were mostly spatial and demographic factors which included the final location and spacing of a transit stop. For example, transit planner can change the location of transit stop to make the accessibility better to match the service standards. Fixed factors also included some design factors which cannot be removed from the stop. For example, vertical gap or horizontal gap can be reduced to suit the service standards but they can never be removed.

- **Binary Factors:** These were the design factors that could be removed or added to increase the transit stop efficiency. For example, information provision (static schedule information, real-time information, etc.), basic and enhanced amenities (shelter, seats, heating and air conditioning system, Wi-Fi, etc.), and security factors (stop light, CCTV camera and emergency service phone).

Indicators were also classified into 2 areas of assessment based on their controllability. Controllability was defined as the ability of transit planner to indirectly change the indicator value to suit the best-practices. Two categories of indicators are:

- **Build Indicators:** These indicators were dictated by build environment and transit planner has no direct control over them, however transit planner can control them indirectly by changing the location of transit stops. For example, transit planner can change the walking distance or number of transit users by changing the location of transit stop.

- **Uncontrolled Indicators:** These were indicators on which transit planner has no control at all. For example, “prevailing temperature” (indicator) for providing “heating system” (factor), or “average daily precipitation” (indicator) for providing “shelter” (factor). Based on the indicator values, these factors can be either added in the transit stop or removed from the transit stops to increase the transit stop efficiency.
Broadly, as shown in Figure 4-1, factors and indicators can be divided into stop-related (i.e. factors related to stop spacing, location, and design) and operation-related (i.e. factors related to level-of-service).

![Figure 4-1: Categories of Factors Effecting Ridership](image)

Out of transit stop and operational factors/indicators, this study was focused on the transit stop factors/indicators only. As explained in Section 2.2, the determination of transit stop location is of vital importance. The location of transit stop is an important factor which impact the passenger safety and maintaining the level of service (Diab and El-Geneidy 2015). Passenger’s perception about the transit service is dependent on the day to day performance of transit and their variability in schedule of arriving the particular transit stop (Bates et al. 2001). The schedule of transit system is dependent on the average speed of transit which intern is dependent on the transit stop location and spacing (U.S. Department of Transportaion Washington D.C. 2014). In addition, the transit stop planning also affects the transit emissions (J. Li et al. 2012) and intra-vehicle conflicts (Koshy and Arasan 2005). The reliability of transit system can be improved by reducing the stop (and dwell) time which is a considerable time in total transit time.
and in-fact is also dependent on the transit stop design (Diab and El-Geneidy 2015) (Levine and Torng 1997).

One of the spatial factors are single land-use (employment, residential, commercial, and educational) and mixed land-use strategies. More dense locations are proved to be more beneficial for transit operations. Among all, residential and employment densities are more important, as suggested by TCRP (1996). Employment density has been studied by several researchers like Liu (1993) and Kain and Liu (1999) who found that the increase of employment density in transit stop catchment area leads to increase in the transit ridership. The employment density of Central Business District has a very pronounce effect on the transit ridership which is further enhanced if metropolitan population is also taken into account (Hendrickson 1986).

Demographical factors include the income level, car ownership, car use, gasoline price and parking cost. Out of all others, the income level is of utmost importance for calculating the transit ridership (Liu 1993)(McLeod et al. 1991)(Gomez-Ibanez 1996). Similarly, the inter-relationship between auto-ownership, car use and transit use was studied by Liu (1993) and Kain and Liu (1996) who showed that they are all linked, and change in one directly affect others. However, in another study Kitamura (1989) showed that the improvement in transit cannot decrease the car ridership. The other main factors affecting the transit are the parking space and parking price. If the parking price is higher or parking space is limited, it tends to increase the transit ridership (TCRP 1998), but the parking space and parking rate are controlled by city governments and transit agency has no control over these factors.

The increase in quality of service is more important factor to increase the ridership than decreasing the fare or increasing the quantity of service (Cervero 1990)(Syed and Khan. 2000). The most important factor in quality of service improving ridership is transit information, followed by on-street service, stop safety, customer service, cleanliness, and general attitude towards security. Transit information, stop safety, and many others are directly related to transit stop design which includes seat, shelter, heating system, fixed time schedule, real transit position, information map, gap-distance, and slopes etc. A proper transit stop design improves rider satisfaction and gives a perception of shorter waiting time, which leads to greater ridership.
and enhances the safer environment. Transit stop design is important because the commuters spend a large amount of time waiting or transfer and if the comfort of commuters at that time is enhanced, this will in turn increase ridership (Taylor et al. 2009).

4.3 Hierarchical Chart for Transit Stop Evaluation

Being the first point of contact between the transit riders and the transit service, transit stops can greatly influence passengers’ perception and service performance. Transit stop planning is a complex process that involves many factors that affect passengers’ perception. Such factors can be classified into two major groups: spatial and demographic factors and design factors. The transit stop planning depend on passenger demand which is uncertain in nature (Fitzpatrick et al. 1996). To satisfy transit demand and facilitate intermodal transfers, transit stops need to be suitably spaced and located within proximity from major trip generators. Therefore, accessibility, land use, and demographics within transit stop catchment area are important to consider in transit stop planning. Beside the spatial and demographic factors, the design of transit stops (i.e. layout, configuration, and amenities) is an integral part of transit stop planning. Transit stop design entails various factors, such as availability of shelter, seats, and schedule/real-time information among others, that affects passengers’ satisfaction. The hierarchical chart developed in this study is shown in Figure 4-2 below.

4.3.1 Spatial and Demographical Factors

The location of a transit stop is a designated place for passengers to board or alight. Transit stop location is normally marked by a simple pole and flag, or a shelter for stops at major transit locations (Galland, Lamotte, and Gaud 2011). The location of a transit stop is critical to the safety of passengers and motorists, as well as the operation of the transit service (El-Geneidy et al. 2006). Proper transit stop location planning should take several factors into consideration, which include:

- Accessibility: It is one of the basic factors for decision-maker (i.e. transit planner or engineer) that transit stop is accessible for patrons of all ages and abilities specially by walking. Therefore, transit stops on steep gradients are discouraged (BC Transit 2010). The passenger access and egress time is crucially affected by the transit stop spacing. To study the access and egress time, a theoretical mathematical model was formed based on
boarding demand per unit length. It was found that an equal distribution of passengers is important to be considered while deciding transit stop spacing to maintain the egress and access time (XIN et al. 2014). Similarly, to increase stop spacing, park-and-ride facility should be provided at appropriate stops where residential density is medium to low (Center for Urban Transportation Research 2009).

- Land use within stop catchment area: Proximity of transit stops to major trip generators (e.g. shopping centers, hospitals, etc.) is important to generate high ridership (BC Transit 2010). For a better utilization of the transit service, transit stops need to be located within areas of high population, employment densities and mixed land use (Cervero 2004) (Kockelman 1995) (Chatman 2008) (Dittmar and Poticha 2004). Land use is also related to the population density, which is the most popular measure for transit agencies to provide facility (Center for Urban Transportation Research 2009). Single land use or multi land use has a strong effect on transit ridership. Multi land use or mix of land use is best represented by entropy which is a measure to determine how evenly different land uses are distributed in an area. The value of entropy varies from 0 to 1, where 0 represents a single land use and it increase with increase of diversity and reach 1 which represents the even distribution of mix land use. This entropy index is directly related to the ridership. According to a research, 0.12% of transit use is increased by increasing 1% of mixed land use parameters (Rahman 2016). Entropy can be calculated by Equation 4-1.

\[
\text{Entropy} = - \sum_{j} \left[ P_j \cdot \ln P_j \right] / \ln J
\]

Where \( P_j \) is the proportion of land developed of the \( j \)th type and \( J \) is the number of different land use types.

- Demographics within stop catchment area: The potential ridership areas can be identified where the household income is low, have no personal vehicle or the number of elderly people or youth is high.

On the other hand, from passengers’ perspective, transit stop spacing reflects the trade-off between increased accessibility of closely spaced stops and decreased travel times of less
frequent stops. From operators’ point of view, transit stop spacing involves a trade-off between increased service coverage of closely spaced stops and decreased fixed/operating cost of less frequent stops (Garrett 2014). Therefore, adequate transit stop spacing can enhance passengers’ perceptions and transit system performance (Murray 2003). Nevertheless, transit stop spacing should be improved as much as possible to correspond to passenger demand (BC Transit 2010).

4.3.2 Design Factors
Physical design of transit stops is an important element that affects passengers’ perception and service performance. It ensures safety and efficiency of transit vehicles and their interaction with transit passengers. Stop design refers to proper transit stop visibility, safe passenger access, amenities for passenger comfort, and universal access (BC Transit 2010). Design criterions mainly include;

- Information provision: On-time performance of transit agency is the percentage of transit units arriving or departing from a transit stop within the specific time frame as being appeared at the static schedule information (Center for Urban Tranportation Research 2009). Transit stop board is an important component of transit stop design. Passenger can quickly find the required information from an appropriate transit stop board, besides, it also depicts the civilization of society. The problems with transit stop boards are mainly the incomplete transit information, lack of traffic information and low humanity. Therefore, a new customer oriented transit stop board was proposed which contain the geographical map, important locations of the city, line index table, and station index table (Fitzpatrick et al. 1997). For this, three types of information provisions are usually used; static schedule information, real time information, and information map.

- Amenities for passenger comfort: Amenities can be divided into basic amenities and enhanced amenities. The provision of amenities at a particular transit stop mainly depends on the local conditions (BC Transit 2010). Basic amenities include shelter, seats, and stop sign. Whereas, enhanced amenities include Wi-Fi, vending/ticket machine, and providing heating system at transit stops. For providing amenities, those stops should be given priority which has large number of transit users, waiting time is long, transfer rate is more, or the weather is unpredictable (Center for Urban Tranportation Research 2009). Thermal environment is important for places having
extreme situations. The transit stop climate is affected by regional, local and site factors (Nikolopoulou et al. 2011) (Kleerekoper et al. 2012) (Chun and Tamura 2005). Shelter is important for wind protection. Wind protection is difficult to design because of its dual nature of acceptance. The uncertainty in predicting the wind condition is also very large and metrological department cannot provide the exact wind conditions for transit stop location. However, as a guideline, less than 5m/s are considered as a pleasant breeze while above 5m/s cause difficulty to walk (Giddings et al. 2011) (Penwarden and Wise 1975) (Nikolopoulou 2004).

- Equity and safety of passengers from accidents: Safety of every passenger is the key for transit agency to maintain standards (Center for Urban Tranportation Research 2009). Safety at transit stop is considered as one of the major concern for transit users which include safety from physical hazards like slippery surface (Taylor et al. 2009). Safety at transit stop can be improved by the shared spaces in which separation between travel modes are removed which results in high visual contact. Higher visual contact between passengers has proven to be better for safety accidents prevention because people act more carefully under these conditions (Hamilton Baillie and Jones 2005) (Kaparias et al. 2012). Equity encourages the community to engage and co-develop the transit policies and made decisions for equitable outcomes. Equity policy grows ridership, improve internal and external customer satisfaction and enhance safety and security (Metro Transit 2016). Four aspects of equity and safety are normally considered which include surface marking, sidewalk corridor, vertical gap, and horizontal gap. Horizontal and vertical gap between transit and platform is a major concern for elderly people, people with walking disabilities, parent having children in pushchairs and wheel chair users. Based on a survey, accessibility of persons with reduced mobility was a concern for almost 25% of transit providers.

- Security from crime: Among other factors, visual comfort and security is of vital importance (Zhang 2012). Characteristics of transit stops can be enhanced to increase personal security. This includes proper light at stop, providing public phone and CCTV cameras. Lightening should be optimum so that waiting area is properly illuminated at night.
Figure 4-2: Hierarchical Chart of Attributes and Indicators for Transit Stop Planning
4.4 Uncertainties in Transit Stop Planning

In this study, uncertainties associated with transit planning were classified as:

1. Parametric Uncertainty
2. Model Uncertainty
3. Scenario Uncertainty

The relevance of categories defined in this study and categories defined by Rowe (1975) and Mahmassani (1984), as discussed in Section 2.3.3, are shown in Figure 4-3.

4.4.1 Parametric Uncertainties

Parameter uncertainty is an estimate of an indicator in the model. As explained in Section 2.3, the values for indicators obtained from agency manuals and published literature are different. This varying benchmark adds the parametric uncertainty into the model.

- Uncertainty also emerges from the measuring instrument being used. For example, in measuring the actual vertical and horizontal gap at a transit stop, precise measurement cannot be possible. Practically, the person measuring the gap can only estimate the gap or calibrate it with some measured scale. This inability of measuring accurate gap also adds uncertainty in model.

- Parameter uncertainties also occur when general data is used to evaluate a transit stop. For example, none of the agency manual or published literature says anything on when to provide the amenities depending on the city size. Therefore, if the same general guidelines are applied to small city or a metropolitan area, this would also add uncertainty to the model.

- Some other sources of parametric uncertainty are:
  - Not considering the superimposed effect of several factors onto each other, while focusing only on few. This leads to miscalculations of the model.
  - Not choosing the right sample size of population to develop the benchmarks of membership functions. This leads to random sampling error and non-representativeness.
4.4.2 Model Uncertainties

Uncertainties occur in the model structure being used for transit stop evaluation, when simplified assumptions are made to reach the endpoint. It includes the choice of probability distribution to characterize variability, and interpolation or extrapolation beyond the scale used to calibrate a
model from empirical data. In transit planning, this may refer specifically to a statistical concept of uncertainty in estimates of population parameters (e.g., arithmetic mean, standard deviation) from random samples, due to the quality, quantity, and representativeness of available data as well as the statistical estimation method adopted.

The model uncertainties also occur if predictions and assumptions are drawn from scientific theories based on a simple linear relationship. For example, it is a common understanding that expertise increases with experience. However, extending this relationship beyond the acceptable limit is a reason for model uncertainty. Some model uncertainties also occur due to wrong relationships called relationship error. For example, in this model, the spacing of transit stop is dependent on the density of catchment area. However, if there is another indicator which also needs to be considered, this will be a source of model uncertainty. Over simplified representations of reality can also be a cause of this uncertainty. Any model is incomplete if it does not cover every indicator affecting the system or uses some referral material for measuring the difficult indicators. For example, the socio-demographics of a catchment never remain same. But these indicator values are estimated from the census which is not the true picture of area. All these factors make the model uncertain to give proper results.

### 4.4.3 Scenario Uncertainties

Scenario uncertainty deals with missing or incomplete information to fully define the system. Most of the design considerations of transit stop depend on passenger demand (Fitzpatrick et al. 1996) (BC Transit 2010) (OCTA 2004) (Hunter Zaworski 2003) (Xin et al. 2014) (Xin et al. 2014) (Tyler et al. 2002). But the number of transit users in a specific locality is uncertain and to design and locate the transit stop under these uncertainties is a difficult task. This is also called demand uncertainty (Kulshrestha et al. 2014). Traffic congestion in metro cities cannot be measured and treated as a uniform input. The traditional analysis methods are not able to give a true picture of roadway condition because of imprecise measurement, traveler’s perception of acceptability, variation in sample data and analyst’s uncertainty about casual relations. In same condition, one may perceive road to be heavily congested while other may perceive it to be slightly congested. Mostly, the transit trip planning is based on an average value of factors involved and do not dynamically respond to the change in traffic and roadway conditions. In real
life, the transit trip planning is effected by uncertain conditions of accidents, traffic delays, passenger boarding and alighting activities and error in public transit positioning system (J.-Q. Li et al. 2012). A realistic model which incorporates uncertainty leads to problems that are computationally difficult to solve (Nikolova et al. 2006). Key information needed in journey planning cannot be dealt with deterministic approaches. Similarly, Uncertainties in transit arrival times results in missed connections, causing negative impact on actual arriving time. To cater these uncertainties, likelihood of user to catch a transit at specific transit stop was studied dealing with user’s estimated time of arrival and transit estimated time of arrival. Other factors which cause uncertainty includes origin and destination locations, start time, transportation means, expected walking or cycling time and number of vehicles used in the trip (Botea et al. 2013).

4.5 Summary

This chapter described the phase – 1 of this study which was about the research methodology adopted to classify different factors and indicators to form a hierarchical chart. It also elaborated on the relationship of uncertainties defined in this study with previous studies. Next chapter will discuss about the expert opinion survey, its design and findings.
Chapter 5: Expert Opinion Survey

5.1 Outline
This chapter is about the expert opinion survey which was designed to collect the best-practices and prioritization of factors and indicators. While section 5.2 discusses the objectives of survey, survey design and implementation are discussed in Section 5.3 and 5.4, respectively. Section 5.5 deals with validity, reliability and survey response analysis methods and final results are discussed in Section 5.6. Section 5.7 emphasizes the need of an index based decision support tool for transit stop planning. Section 5.8 concludes the chapter.

5.2 Survey Planning
In survey planning phase, the first step is to define the survey objectives, design the survey instrument, and design survey sample accordingly (Idris et al. 2012). As stated in Section 2.3, the agency guidelines and published literature does not give the best-practices for all indicators related to transit stops. Furthermore, indicators for which the guidelines are given, they are not classified according to city size. The inter-dependency of factors is also not yet studied. Therefore, the main objectives of this survey were to;

1. Develop detailed best-practices for indicators related to transit stops for large and small cities of Canada.
2. Develop priority ranking of indicators and factors from expert point of view.

5.3 Survey Design and Development
5.3.1 Survey Population
CUTA categorize Canadian cities into five categories according to the city population, as shown in Table 1-1. Maximum number of people resides in small or rural communities, which accounts for maximum area and minimum density. In this study, two categories of cities were defined, large cities and small cities. Major metropolitan areas and large cities were combined to form large cities having population more than 400,000. Similarly, medium cities, small cities and small and rural communities were combined to form small cities having population less than 400,000. Data about number of transit agencies operating in cites were collected from the city websites. For some cities, one transit agency covers more than one city. For example, BC Transit covers Prince George, Victoria, Nanaimo, Kamloops, Saanich, Kelowna, and many other small
and rural communities. Over and all, it is inferred that transit facility covers every small, medium, large, and major metropolitan city of Canada. Table 5-1 shows statistics about 5 categories of cities.

Table 5-1: Statistics about 5 Categories of Canadian Cities
(Statistics Canada, 2011)

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Category</th>
<th>Population Change</th>
<th>Land Area</th>
<th>Average Population Density</th>
<th>No. of Cities</th>
<th>No. of Transit Agencies</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>percentage</td>
<td>square kilometres</td>
<td>per square kilometre</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Large cities</td>
<td>4.50</td>
<td>630.21</td>
<td>4,149.47</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Large Cities</td>
<td>7.63</td>
<td>7,937.64</td>
<td>1,928.68</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>3</td>
<td>Small cities</td>
<td>7.77</td>
<td>11,719.87</td>
<td>1,184.99</td>
<td>17</td>
<td>20</td>
</tr>
<tr>
<td>4</td>
<td>Medium Cities</td>
<td>6.23</td>
<td>87,446.92</td>
<td>749.89</td>
<td>67</td>
<td>45</td>
</tr>
<tr>
<td>5</td>
<td>Small and Rural Communities</td>
<td>4.23</td>
<td>8,857,386</td>
<td>156.11</td>
<td>5,156</td>
<td>Many</td>
</tr>
</tbody>
</table>

For this survey, the total population was transit-planning experts across Canada. However, the contact information of every expert was impossible to collect. Therefore, instead of contacting transit agencies for transit planners, some professional bodies and platform exists and it is expected that the transit planners will be a member of these bodies. For example, CUTA is a body of professionals working in transit systems; federal, provincial and regional/municipal government agencies; business members; companies or persons engaged in the manufacture or sale of transit equipment or services; and affiliates (CUTA 2014). The membership directory (CUTA 2017) is a closed data source having specific contact details of all the CUTA-members dealing in field of transit systems, consultant, governments agencies, suppliers and other affiliate members. The transit experts retrieved from CUTA membership directory were found to be 379.

5.3.2 Instrument Design
As explained before, this survey was conducted to collect the experts’ opinion working in the public transit planning industry. The factors and indicators described in Section 3.2.1 were
shared with the transit planners in a web survey. Expert opinions are more useful because of the open-ended questions so that best opinion can be captured (Couper et al. 2001).

For expert opinion survey, the focus was to collect prioritization (Section A of expert opinion survey) and best-practices (Section B of expert opinion survey) of transit stop planning factors/indicators. Figure 5-1 shows the complete flowchart of survey instrument design, whereas, the complete survey is presented in the Appendix. Following section will describe the two sections of expert opinion survey (Section A and Section B) in detail.

An online questionnaire was used to collect responses. The collection of population and sample size is explained in Section 5.3.1. The respondents were contacted through email with a link to questionnaire. The UBC Survey Tool used to design the survey questionnaire. As illustrated in Figure 5-1, the expert survey was divided into the following 5 sections:

1. Consent and Introduction
2. Professional Information
3. Section A: Prioritization of factors and indicators
4. Section B: Best-practices of indicators
5. Survey Feedback and Submission

While professional information and survey feedback sections were added to categorize results according to city size and perform content validity index check, the main body of the survey was comprised of Section A and Section B, as explained below.
Section A gathered the detailed prioritization of transit stop planning factors and indicators. In general, pair wise comparison technique was used to collect data about prioritization. First the indicators of spatial and demographics were arranged followed by their factors which were then followed by the design indicators and factors. At the start of section, an explanatory example was provided to help the respondents understand how to fill the questionnaire, as shown in the Figure 5-1: Survey Instrument Design.
Appendix. Furthermore, the option of example was kept at start of every page, but by default, this was hidden. Bipolar Likert scale and pair wise comparison was used to decide the weights of each factor and indicator. Although 5 to 9-point uni-polar-Likert scales are normally used, but in this survey, a 5-point-bi-polar Likert scale was used. Figure 5-2 shows a snapshot of Section A for expert opinion survey.

In Likert scale of section A, the intensity level chosen were “strongly more important”, “more important” or “equally important”. Of the two factors provided, position of “hand” showed the more important factor and its intensity. Section A answered the question that which factor is more important in transit stop planning for an efficient stop planning. As stated earlier, past research lacked the inference that how improvements at transit stop will increase the ridership. Most of previous research dealt with the design perspective of transit stop independently. For example, providing seats and shelter at stop might increase ridership but which of these is more important, this was not available in any agency manual or published literature. This lack of mutual dependency makes it difficult for transit planners to design a transit stop.
Which of the following **stop location factors** is more important to increase transit ridership?

- **Access by walk/cycle**
- **Access/egress distance to/from the stop by walk/cycle**
- **Average household income within stop catchment area**
- **Percent of seniors (≥ 60 years) within stop catchment area**
- **Accessibility to/from stop (walking/cycling distance and longitudinal slope)**
- **Accessibility to/from stop (walking/cycling distance and longitudinal slope)**

**Figure 5-2: Screenshot for Section A of Survey (Prioritization)**
5.3.2.2 Section B: Best-practices of Indicators

Section B was about with the best-practices in transit stop planning. Just like Section A, Section B started with an explanatory example which was also available on start of every page but kept hidden by default. The explanatory example of Section B is shown in Figure 5-3. Two cases were presented in this example. By default, Case 1 was selected in which experts classified the best-practices into 3 classes of “Excellent”, “Acceptable” and “Unacceptable”. However, if the experts selected the second case, case 2, they provided benchmarks for only 1 class of “Acceptable”.

For best-practices, several agency manuals and published literature are available which differ from each other, as explained in Section 2.3. Further, all these literature and manuals adopts a deterministic approach towards stop planning. None of them give detailed ranges about indicators. For example, according to operational impacts of transit stops (Tyler et al. 2002), if the horizontal and vertical gap is less than 50 mm, it is said to be in perfect range. If it exceeds and still is less than 100 mm, it can be accessed but with a little difficulty. And, if it is more than 100 mm, then is not accessed at all. There is no other indicator about which such detailed best-practices are provided. Even for horizontal and vertical gap, other literature gives different ranges. For example, NACTO (2016) does not give any such categories and simply says that horizontal gap should be less than 76 mm. In another study, Dejeammes et al. (1999) found that horizontal gap can go up-to 300 mm. Taking vertical gap into consideration, the guidelines from operational impacts of transit stop stands still whereas NACTO (2016) limits it to less than 16 mm.
CASE 1: Factors with three-level ranges
(i.e. Excellent, Acceptable, and Unacceptable)

Assume that the typical ranges for walk distance to/from a street transit stop are as follows:

<table>
<thead>
<tr>
<th>Range Level</th>
<th>Range (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>0 - 400</td>
</tr>
<tr>
<td>Acceptable</td>
<td>400 - 800</td>
</tr>
<tr>
<td>Unacceptable</td>
<td>&gt; 800</td>
</tr>
</tbody>
</table>

You can enter the previous information into the survey tool as follows:

CASE 2: Factors with one-level ranges
(i.e. Acceptable / Unacceptable)

Assume that the typical range for walk distance to/from a street transit stop is as follows:

<table>
<thead>
<tr>
<th>Range Level</th>
<th>Range (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceptable</td>
<td>≤ 400</td>
</tr>
</tbody>
</table>

You can enter the previous information into the survey tool as follows:

Figure 5-3: Explanatory Example for Section B of Survey (Best-practices)
To cover all these differences, case one of this survey was a tri-category approach of best-practices, i.e. “Excellent”, “Acceptable” and “Unacceptable”. Research on human capacity to deal with information has shown that there are some limitations on the amount of information that humans can retrieve, process, and remember. Based on those limitations, an average number of elements that a human can process is seven, plus or minus two (Miller 1956). Some researchers also recommend to keep categories less than seven for better understanding (Karwowski and Mital 1986). The number of categories can be defined by experts and can range from a minimum of three to a maximum of eleven qualitative levels (Khan and Sadiq 2005) (Sadiq et al. 2004). Main purpose of this survey was to capture diversity of expert opinion. Therefore, this survey adopted the number of categories corresponding to a certain indicator to three. The approach of (Khatri et al. 2011) was adopted in this survey. The best-practices were gathered and shared with the experts in survey. Figure 5-4 shows a screenshot of survey Section B.

The survey was so designed that the upper limit of “Excellent” category was auto-filled in the lower limit of “Acceptable” category. Similarly, upper limit of “Acceptable” category was auto-filled in lower limit of “Unacceptable” category. This is more clearly visualized in Figure 5-3.

For Case – 2, a binary approach was adopted to collect best-practices. This is the traditional form of applying best-practices in transit stop planning and is available in almost every agency manual and available literature. Mostly, city governments are important stakeholder in the stop planning. As explained in Section 2.3, city government has an allocated budget for transit related developments including transit stops. These funds are allocated to city governments according to city size which is a function of city population. But no manual or literature gives best-practices as a function of city population. For example, BC Transit operates from small towns to large urban centers across British Columbia. But the Infrastructure Design Guidelines by BC Transit (2010) does not give guidelines about amenities according to city size rather gives in a generic manner. The Case 2 of Section B developed guidelines according to the city size, but not as a detailed tri-category approach rather traditional binary approach. Figure 5-5 shows screenshot of binary approach of survey.
Question 30: Stop Spacing - Central Business District (CBD)

Best-practices in transit service planning suggest following values/ranges for the street transit (e.g. bus and streetcar) stop spacing in Central Business District:

- Stop spacing can range from 200m to 300m, but typically can be 200m

- For the central core/CBD, the stop spacing should be 90 to 300m; a typical spacing is 180m

- Stop spacing can typically be 400m (Reference: https://at.govt.nz/media/imported/4394/AT-ARTA-Guidelines-Bus%20Stop%20Infrastructure%20Guidelines%202009.pdf).

Please enter the typical values/ranges you would recommend for the above-mentioned factor into the designated cells below.

Enter as three-level ranges

Enter as one-level range

I Don't Know

For any other comments/additional indicators, please fill the textbox below:

Type here
Question 30: Stop Spacing - Central Business District (CBD)

Best-practices in transit service planning suggest following values/ranges for the street transit (e.g. bus and streetcar) stop spacing in Central Business District:

- Stop spacing can range from 200m to 300m, but typically can be 200m (Reference: [https://bctransit.com/servlet/documents/1403640670226](https://bctransit.com/servlet/documents/1403640670226)).

- For the central core/CBD, the stop spacing should be 90 to 300m; a typical spacing is 180m (Reference: [https://www.nctr.usf.edu/pdf/77720.pdf](https://www.nctr.usf.edu/pdf/77720.pdf)).

- Stop spacing can typically be 400m (Reference: [https://at.govt.nz/media/imported/4394/ATARTAGuidelines-Bus%20Stop%20Infrastructure%20Guidelines%202009.pdf](https://at.govt.nz/media/imported/4394/ATARTAGuidelines-Bus%20Stop%20Infrastructure%20Guidelines%202009.pdf)).

Please enter the typical values/ranges you would recommend for the above-mentioned factor into the designated cells below.

Figure 5-5: Screenshot for Section B of Survey (Collecting Binary Best-practices)
Option 3, “I Don’t Know” gave option to the expert to skip the question and move to next. However, at the end of survey, the experts were not directed to the questions they have skipped. Figure 5-6 shows the screenshot of this option. At the end of each question, a text box was provided to facilitate the experts to give their feedback about the question. For example, in Figure 5-6, the stop spacing was considered as a function of catchment area density (central business district, urban area, sub-urban area or rural area). However, if the expert thought that stop spacing is also dependant on some other indicator, this text box gave space to write the extra comments about indicators.

Every question in Section B was a combination of 4 question types. The statement of question and referred manuals and literature was “Section Heading” type questions and they were not open for any editing by the respondent. The option to choose between Tri-category and Binary case was a “Multiple Choice” question. Only one option could be selected from the three provided options. However, by default, tri-category case was selected. Based on option selected, the categories were shown to be filled by respondent. These were “3D Matrix” type of question. As stated earlier, auto-filled option was pre-programed. Entry in these questions was restricted to number digits only to make computational work easy. At the end, “Text Response” type of question was placed which was an open-ended question.

At the end of survey, the respondent feedback was collected about the selection of factors and indicators. It was a 5-point “Semantic Differential” type of question which is almost like Likert scale question type and varied from strongly agree to strongly disagree going through levels of agree, tend to agree, and disagree. A text box was provided at the end to add any further factor/indicator which also affect the ridership. Screenshot of feedback form is given in Figure 5-7.
Question 30: Stop Spacing - Central Business District (CBD)

Best-practices in transit service planning suggest following values/ranges for the street transit (e.g. bus and streetcar) stop spacing in Central Business District:

- Stop spacing can range from 200m to 300m, but typically can be 200m (Reference: https://bctransit.com/servlet/documents/1403640670226).

- For the central core/CBD, the stop spacing should be 90 to 300m; a typical spacing is 180m (Reference: https://www.nctr.usf.edu/pdf/77720.pdf).

- Stop spacing can typically be 400m (Reference: https://at.govt.nz/media/imported/4394/AT-ARTA-Guidelines-Bus%20Stop%20Infrastructure%20Guidelines%202009.pdf).

Please enter the typical values/ranges you would recommend for the above-mentioned factor into the designated cells below.
Expert Opinion Survey for Street Transit Stop Planning

Show Illustrative Example:

- [ ] Yes
- [ ] No

Feedback on Survey:
Does the survey cover all factors that affect transit ridership?

- [ ] Strongly Agree
- [ ] Agree
- [ ] Disagree
- [ ] Strongly Disagree

Please mention any other factor(s) that can be considered (optional):

Type here

[Back] [Submit]

Figure 5-7: Screenshot for Survey Feedback
5.4 Data Collection Process

5.4.1 Phase – 1

In this study, pilot study was conducted to test the survey instrument design. Pilot survey was carried out from March 8, 2017 to March 17, 2017 among the transportation engineering students and faculty members working at University of British Columbia Okanagan campus. The sample size of pilot survey was 27 individuals consisting of 18 student members, 5 faculty members, and 4 transportation experts working in transportation planning industry. As planned for main survey, they were contacted through email and a link to the survey was provided for access. Being involved in the transportation engineering planning and design, transportation engineering students were believed to have some basic knowledge about transit stop planning and the technical terminologies used in survey. However, some faculty and students outside of transportation engineering were also chosen for pilot survey to validate the survey instrument design. In general, none of pilot survey respondent reported that they cannot understand the layout of questions, however, non-technical respondents reported their limited knowledge about survey factors/indicators.

For the pilot survey, response rate was recorded to be 74%. From pilot survey, the responses of four experts were of utmost importance. Out of four, three experts completed the survey whereas one expert completed only Part A of survey. After analyzing the responses from experts, factors and indicators were further refined. After analyzing the results of both Part A and Part B, five factors were removed and two indicators were added. Those factors were removed which fulfill the following two criterions:

1. After analyzing the responses of four experts, the factor showed a very low weight as compared to other.
2. In Section B, at least one expert said that this factor is not important at all and should not be considered in street transit stop planning.

By analyzing the pilot survey findings, factors/indicators were divided into four classes; factors which meet both of above stated criterions, factors which meet at least one criterion, factors which do not meet any criterion and indicators which were suggested by the experts. For example, garbage receptacles were added in the factor chart for pilot survey but the experts gave
it a weight of 0.099 as compared to 0.37 for shelter, 0.238 for seats, and 0.293 for transit stop flag in the same category. It inferred that it is of least importance, and met criterion number one. Further, one of the expert suggested that garbage receptacles are important for the people living in the transit stop vicinity but it is not important for increasing the ridership, which met criterion number two. Therefore, garbage receptacles (and all other factors meeting both criterions) were removed from the factor chart. Similarly, few factors/indicators were added in the factor chart, as suggested by the experts. For example, to provide heating system, two indicators used in agency manuals were the temperature of catchment area and number of transit users. Past literature suggests that heating system is required if temperature goes below -3°C. However, the responses collected from pilot survey suggested that temperature of catchment area is not a suitable indicator. Suppose that temperature goes below -3°C for one week in a year, a heating system will be too costly and would not be working for almost complete year. Therefore, pilot survey suggested that weeks of freezing temperature in which temperature goes below -3°C is more appropriate indicator. Therefore, considering pilot survey results, factors/indicators were replaced and new factors/indicators were added.

After completely analyzing the pilot survey; factor chart and online survey were revised and phase – 2 (full survey) was launched after UBC Okanagan Campus Behavioural Research Ethics Board approval. Section 5.4.2 discusses the phase – 2 of survey.

### 5.4.2 Phase – 2

As discussed above, the survey were conducted in two phases. Phase – 1 was the pilot survey whereas phase – 2 was the main survey. The findings and suggestions from phase – 1 was implemented in phase – 2 to get a better response rate. The list of transit planners was collected from CUTA. After conducting phase – 1, pilot survey, till March 17, 2017, phase – 2, main surveys were conducted from April 12, 2017 to April 28, 2017. The question count for Part A of survey (prioritization of factors and indicators) was 11 while for Part B (best-practices of indicators) was 34. Table 5-2 below shows some statistics of surveys.
<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Description</th>
<th>Abbreviation</th>
<th>Survey Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Expert Opinion Survey</td>
<td></td>
<td>Complete/Till Part A</td>
</tr>
<tr>
<td>1</td>
<td>Target Population Size</td>
<td>N</td>
<td>379</td>
</tr>
<tr>
<td>2</td>
<td>Response Received</td>
<td>R</td>
<td>111/172</td>
</tr>
<tr>
<td>3</td>
<td>Response Rate (%)</td>
<td>RR</td>
<td>≈30/≈45</td>
</tr>
</tbody>
</table>

### 5.5 Survey and Data Analysis

#### 5.5.1 Survey Validation Tests

As explained in Section 2.4.2, content and construct validation are two major types of survey validation tests. Survey content was validated using content validity index whereas survey construct was validated using t-test. In this survey, content validity index was calculated using the survey feedback question shown in Figure 5-7 and the final results are shown in Section 5.6.2. Similarly, survey construct was validated using t-test. The procedure for applying t-test is described below.

As discussed in Section 5.3.2.2, three classes of best-practices were defined to develop the guidelines. Let’s suppose that few experts (say, 5) from one city size category (say, small city) provided best-practices about a factor (say, seats, i.e. number of transit users required to provide seats), as shown in Table 5-3.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Years of Experience</th>
<th>Excellent</th>
<th>Acceptable</th>
<th>Unacceptable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>LL</td>
<td>UL</td>
<td>LL</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>00</td>
<td>400</td>
<td>400</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>99</td>
<td>466</td>
<td>466</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>64</td>
<td>566</td>
<td>566</td>
</tr>
<tr>
<td>4</td>
<td>15</td>
<td>92</td>
<td>528</td>
<td>528</td>
</tr>
<tr>
<td>5</td>
<td>25</td>
<td>30</td>
<td>490</td>
<td>490</td>
</tr>
</tbody>
</table>

For construct validity, t-test was used for pattern matching on the lower limit (LL) and upper limit (UL) of every category. By construct, it is evident that these two limits can never be the
same. Therefore, responses collected from the respondents were analyzed by t-test to show that these two limits differ or remained same. If they differ, it means that the construct is valid and if they remained same, it means that construct is invalid.

Following the procedure of t-test given in Section 2.4.2.2, the basic hypothesis formulated for construct validity were the following:

\[ H_0: \text{lower limit} = \text{upper limit} \]
\[ H_1: \text{limit} \neq \text{upper limit} \]

\( H_0 \) reflects the null hypothesis and \( H_1 \) is called the alternative hypothesis. In this case, alternative hypothesis can also be called as two-sided alternative hypothesis because it would be true if “lower limit < upper limit” or if “lower limit > upper limit”. The vary basic of hypothesis testing lies in sampling distribution.

Year of experience has a profound impact on the achieved expertise level. For example, it is said that to master chess, chess player should spend about 30,000 hours at game. Radiologists examine almost 10,000 x-rays during medical training, and physicians see 25 patients a day in a typical scenario (Ashton 1991). Similarly, in engineering, the expertise increases with experience. Therefore, in this study, weighted additive mean was used. Weighing scheme was derived from the report of ASCE survey (2012) and are given in Table 5-4:

<table>
<thead>
<tr>
<th>Years of Experience</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Absolute weights</td>
</tr>
<tr>
<td>&lt; 1</td>
<td>1</td>
</tr>
<tr>
<td>1 – 2</td>
<td>1.5</td>
</tr>
<tr>
<td>3 – 4</td>
<td>3.5</td>
</tr>
<tr>
<td>5 – 9</td>
<td>7</td>
</tr>
<tr>
<td>10 – 14</td>
<td>12</td>
</tr>
<tr>
<td>15 – 19</td>
<td>17</td>
</tr>
<tr>
<td>20 – 24</td>
<td>22</td>
</tr>
<tr>
<td>≥ 25</td>
<td>25</td>
</tr>
</tbody>
</table>
Table 5-5 shows the hypothesis testing results of assumed example shown in Table 5-3.

### Table 5-5: Hypothesis Testing Results for Construct Validity

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Variable</th>
<th>Excellent</th>
<th>Acceptable</th>
<th>Unacceptable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Weighted additive mean ( y_i )</td>
<td>60.2</td>
<td>509.1</td>
<td>930.4</td>
</tr>
<tr>
<td>2</td>
<td>Sample size ( n_i )</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>Standard deviation ( S_i )</td>
<td>41.88</td>
<td>63.04</td>
<td>104.16</td>
</tr>
</tbody>
</table>

### 4. T-test

<table>
<thead>
<tr>
<th></th>
<th>Excellent</th>
<th>Acceptable</th>
<th>Unacceptable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard deviation ( S_p )</td>
<td>53.52</td>
<td>86.09</td>
<td>141.74</td>
</tr>
<tr>
<td>Sample t-test ( t_0 )</td>
<td>-13.264</td>
<td>-7.737</td>
<td>-4.969</td>
</tr>
<tr>
<td>Significance level ( \alpha )</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>t-test distribution ( t )</td>
<td>2.75</td>
<td>2.75</td>
<td>2.75</td>
</tr>
<tr>
<td>Final result</td>
<td>Null hypothesis failed</td>
<td>Null hypothesis failed</td>
<td>Null hypothesis failed</td>
</tr>
</tbody>
</table>

Failure of null hypothesis means that lower limit and upper limits are not equal which validates the construct validity. Detailed results from the survey are discussed in Section 5.6.2.

### 5.5.2 Survey Reliability Tests

As discussed in Section 2.4.3, survey reliability is an estimate of degree up to which survey results can be generalized from a small sample to large population. In this study, Cronbach’s alpha is used to estimate the reliability.

In this survey, five-point-bipolar Likert scale was used to collect data from experts. The quantitative nature of Likert scale is converted into qualitative nature using the conversion shown in Table 5-6.

### Table 5-6: Conversion of Qualitative Scale to Quantitative Scale

<table>
<thead>
<tr>
<th>Factor “A”</th>
<th>Qualitative Scale</th>
<th>Factor “B”</th>
<th>Quantitative Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>(say seats)</td>
<td>Strongly more important</td>
<td>More important</td>
<td>Equal</td>
</tr>
<tr>
<td>( 5 )</td>
<td>3</td>
<td>0</td>
<td>( 1/3 = 0.333 )</td>
</tr>
</tbody>
</table>
In Table 5-6, integer shows that factor A is more important than factor B as per the intensity specified, whereas fraction shows the opposite. Let’s suppose that few experts (say, 5) responded to few questions (say, 5) in the manner shown in Table 5-7;

Table 5-7: Explanatory Example for Cronbach’s Alpha Reliability Test

<table>
<thead>
<tr>
<th></th>
<th>Question # 1</th>
<th>Question # 2</th>
<th>Question # 3</th>
<th>Question # 4</th>
<th>Question # 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expert # 1</td>
<td>5.00</td>
<td>3.00</td>
<td>5.00</td>
<td>1.00</td>
<td>3.00</td>
</tr>
<tr>
<td>Expert # 2</td>
<td>3.00</td>
<td>1.00</td>
<td>0.33</td>
<td>3.00</td>
<td>0.20</td>
</tr>
<tr>
<td>Expert # 3</td>
<td>0.20</td>
<td>0.33</td>
<td>1.00</td>
<td>0.20</td>
<td>1.00</td>
</tr>
<tr>
<td>Expert # 4</td>
<td>0.33</td>
<td>0.33</td>
<td>1.00</td>
<td>3.00</td>
<td>3.00</td>
</tr>
<tr>
<td>Expert # 5</td>
<td>0.20</td>
<td>0.33</td>
<td>1.00</td>
<td>3.00</td>
<td>3.00</td>
</tr>
</tbody>
</table>

To analyze the data, SPSS was used in this study which consists of following three tables:

1. Reliability Statistics Table
2. Item Statistics Table
3. Scale Statistics Table

Reliability Statistics table shows the final Cronbach’s alpha value and number of items/questions. Table 5-8 (a) shows the SPSS result of reliability statistics of data shown in Table 5-7.

Table 5-8: Cronbach’s Alpha Results for Explanatory Example
(a): Reliability Statistics Table

<table>
<thead>
<tr>
<th>Cronbach’s Alpha</th>
<th>Cronbach’s Alpha Based on Standardized Items</th>
<th>N of Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.637</td>
<td>0.615</td>
<td>5</td>
</tr>
</tbody>
</table>

Item statistics table shows the mean and standard deviation for each item/question. Table 5-8 (b) shows the SPSS result of reliability statistics of data shown in Table 5-7.
(b): Item Statistics Table

<table>
<thead>
<tr>
<th>Question #</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.7466</td>
<td>2.17588</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>0.9998</td>
<td>1.15484</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>1.6666</td>
<td>1.88568</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>2.0400</td>
<td>1.34462</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>2.0400</td>
<td>1.34462</td>
<td>5</td>
</tr>
</tbody>
</table>

Scale Statistics Table shows the descriptive statistics for the questionnaire as a whole. Table 5-8 (c) shows the SPSS result of reliability statistics of data shown in Table 5-7.

(c): Scale Statistics Table

<table>
<thead>
<tr>
<th>Mean</th>
<th>Variance</th>
<th>Std. Deviation</th>
<th>N of Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.4930</td>
<td>27.018</td>
<td>5.19793</td>
<td>5</td>
</tr>
</tbody>
</table>

Data from Table 5-8(b) and Table 5-8(c) can be used to solve the Equation 2-4 to calculate the final Cronbach’s alpha given in Table 5-8(a). Table 5-8(d) shows the Cronbach’s Alpha calculations of reliability test of data shown in Table 5-7.

Table 5-8(d): Cronbach’s Alpha Calculations

<table>
<thead>
<tr>
<th>Number of Items/Questions</th>
<th>Item Statistics</th>
<th>Scale Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Std. Deviation</td>
<td>Variance</td>
</tr>
<tr>
<td></td>
<td>S_i</td>
<td>S_i^2</td>
</tr>
<tr>
<td>k</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>2.17588</td>
<td>4.73</td>
</tr>
<tr>
<td></td>
<td>1.15484</td>
<td>1.33</td>
</tr>
<tr>
<td></td>
<td>1.88568</td>
<td>3.55</td>
</tr>
<tr>
<td></td>
<td>1.34462</td>
<td>1.80</td>
</tr>
<tr>
<td></td>
<td>1.34462</td>
<td>1.80</td>
</tr>
<tr>
<td></td>
<td>(\Sigma) S_i^2=13.24</td>
<td></td>
</tr>
</tbody>
</table>

\[ \alpha = \frac{5}{4} \left(1 - \frac{13.24}{27.018}\right) \]
\[ \alpha = 0.6374 \]

Detailed results from the survey are discussed in Section 5.6.3.
5.5.3 Survey Data Analysis
The data obtained from surveys were preliminary analyzed according to the city size. The inputs of experts were analyzed using the following methods:

- For Part A of surveys, in which experts provided the prioritization of factors and indicators, the inputs were analyzed by:
  - Taking weighted geometric mean of all the experts’ prioritization, to define a single number for large and small cities.
- For Part B of expert opinion survey, in which experts provided the best-practices of transit stop planning, the inputs were analyzed by:
  - Performing t-test to find if the responses for large cities and small cities benchmarks varied or not;
  - Finding the coefficient of variation (CV) of each level to determine how much is the variation in expert opinion.

The detailed description of result analysis of Part A and Part B is described in next section.

5.5.3.1 Part A: Prioritization of Factors/Indicators
The qualitative scale used in Part A of survey was a bi-polar, five-point Likert scale. The qualitative nature of this scale was changed to quantitative through conversion shown in Table 5-6. Let’s suppose that few experts (say, 5) from one city size category (say, large city) ranked two factors (say, seats and shelter) in following way, as shown in Table 5-9.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Years of experience</th>
<th>Factor “A” (say, seats)</th>
<th>Response</th>
<th>Factor “B” (say, shelter)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Qualitative</td>
<td>Quantitative</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>A – Equal – B</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>A – more important – B</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>B – more important – A</td>
<td>1/3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>15</td>
<td>A – strongly more important – B</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>25</td>
<td>A – more important – B</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>
Geometric mean was considered instead of arithmetic mean because priority decided by the experts is a ratio between two factors/indicators. The weighted geometric mean calculated for inputs assumed in Table 5-9 and using weights given in Table 5-4 is shown below.

Step – 1: Compute the value of each input with an exponent equal to its weight

\[
\begin{align*}
1^{0.02} & = 1.000 \\
3^{0.08} & = 1.092 \\
(1/3)^{0.13} & = 0.867 \\
5^{0.19} & = 1.358 \\
3^{0.28} & = 1.360
\end{align*}
\]

Step – 2: Find geometric mean from these weighted values

Weighted geometric mean =

\[
(1 \times 1.092 \times 0.867 \times 1.358 \times 1.360)^{1/(0.02+0.08+0.13+0.19+0.28)} = 2.221
\]

These calculations showed that Factor A is 2.221 times more important than Factor B. Similarly, other factors/indicators were analyzed in same manner. The final results obtained are shown in Section 5.6.4.

5.5.3.2 Part B: Best-practices of Transit Stop Planning

Best-practices correspond to the practical ranges being used by the experts in planning a transit stop. As explained earlier, the best-practices not only differ by city size, but also from person to person. Therefore, it is important to find two things in capturing the complete best-practices:

1. The weighted additive mean of all the expert opinions
2. The degree of variation of expert opinions

To develop the guidelines, three classes of best-practices were defined. Let’s suppose that few experts (say, 5) from large city provided best-practices about an indicator (say, seats, i.e. number of transit users required to provide seats), as shown in Table 5-10.
Table 5-10: Explanatory Example for Result Analysis of Part B

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Years of Experience</th>
<th>Expert Assumed Best-practices (for large city)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LL</td>
<td>UL</td>
<td>LL</td>
<td>UP</td>
<td>LL</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>00</td>
<td>400</td>
<td>800</td>
<td>800</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>99</td>
<td>466</td>
<td>1040</td>
<td>1040</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>64</td>
<td>566</td>
<td>820</td>
<td>820</td>
</tr>
<tr>
<td>4</td>
<td>15</td>
<td>92</td>
<td>528</td>
<td>890</td>
<td>890</td>
</tr>
<tr>
<td>5</td>
<td>25</td>
<td>30</td>
<td>490</td>
<td>987</td>
<td>987</td>
</tr>
<tr>
<td>TO FIND!!!</td>
<td>(1)</td>
<td>X₁</td>
<td>X₂</td>
<td>X₃</td>
<td>X₄</td>
</tr>
<tr>
<td></td>
<td>Variation in experts’ opinion (X₅)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

LL = Lower Limit  UL = Upper Limit

Final values were calculated by using additive mean, instead of geometric mean because these were the values for a certain category which was independent of any other, as opposite to the ratio in Part A. Weighted additive mean was taken to incorporate the effect of years of experience, as done in Part A. The degree of variation was captured by the coefficient of variation (CV). Coefficient of variation is calculated according to Equation 5-1.

\[
Coefficient \ of \ Variation = \frac{Standard \ Deviation}{Weighted \ Additive \ Mean} \times 100 \quad \text{Equation (5-1)}
\]

The CV of upper level of one category was same as the lower level of next category. The additive average of all CVs gave the final CV of one indicator. Results of assumed example shown in Table 5-10 are given in Table 5-11.

Table 5-11: Hypothesis Testing Results for Part B

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Variable</th>
<th>Excellent</th>
<th>Acceptable</th>
<th>Unacceptable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Weighted additive mean</td>
<td>yᵢ</td>
<td>60.2</td>
<td>509.1</td>
</tr>
<tr>
<td>2</td>
<td>Sample size</td>
<td>nᵢ</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>Standard deviation</td>
<td>Sᵢ</td>
<td>41.88</td>
<td>63.04</td>
</tr>
<tr>
<td>4</td>
<td>Coefficient of Variation</td>
<td>CV’</td>
<td>69.6</td>
<td>12.4</td>
</tr>
<tr>
<td></td>
<td>CV</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
After categorizing the survey responses into large city and small city, these are analyzed by using t-test as discussed under Section 2.4.2.2. However, now null and alternative hypothesis were the following:

\[ H_0: \text{guidelines for small city} = \text{guidelines for large city} \]
\[ H_1: \text{guidelines for small city} \neq \text{guidelines for large city} \]

For those factors, where null hypothesis was passed (i.e. both data sets were equal), only one value for small and large cities was reported, as shown in Table 5-14. However, for those factors where alternative hypothesis was passed (i.e. both data sets were not equal), separate values for small and large cities were reported. Section 5.6.4 shows the final results of best-practices and ranking obtained from survey.

5.6 Survey Results

5.6.1 Respondent Characteristics

The expert opinion survey was divided into two main sections (Section A for prioritization and Section B for best-practices). Out of 379 invitations sent to experts, 172 responses were received which were completed only till Section A while 111 responses were completed till the end (i.e. both Section A and Section B). Geographical distribution of these responses, shown in Figure 5-8, depicts that nearly all provinces of Canada were covered in this survey. Characteristics of the respondents according to city size and year of experience shows that most of the survey respondents were having experience of at least 5 years, as shown in Table 5-12.
Figure 5-8: Geographic Distribution of Experts

Table 5-12: Survey Statistics (Years of Experience)

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Part A</th>
<th></th>
<th>Part B</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Large Cities</td>
<td>Small Cities</td>
<td>Total</td>
<td>Large Cities</td>
<td>Small Cities</td>
</tr>
<tr>
<td>Response w.r.t. years of experience</td>
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<tr>
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<td>29</td>
<td>72</td>
<td>27</td>
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<tr>
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<td><strong>84</strong></td>
<td><strong>172</strong></td>
<td><strong>60</strong></td>
<td><strong>51</strong></td>
</tr>
</tbody>
</table>
5.6.2 Survey Validation Results

As discussed in Section 5.5, survey content and survey construct were validated using content validity index and t-test, respectively. Content validity index is a ratio between the number of experts agreeing to the total number of experts. To validate the content, survey feedback question is shown in Figure 5-7 and the results are shown in Figure 5-9.

From the survey feedback question, 86 out of 111 experts (78%) agreed that the survey covers all the factors and indicators effecting transit ridership. This gave a content validity index of 0.78. As shown in Table 2-3 in Section 2.4.2.1, the CVI decreases with an increase in number of experts. For only 2 experts, CVI needs to be equal to 1.00, whereas, for 10 experts, CVI drops down to 0.8. Similarly, if extrapolated, CVI is expected to further drop while reaching 111 experts. Therefore, it is not unreasonable to conclude that CVI calculated in this study, 0.78, would lie in acceptable dark blue zone. From the survey feedback form, 22% experts did not agree with the statement that survey covers all those factors and indicators effecting ridership. Those experts mentioned some other factors which should be considered in transit stop planning process. Factors suggested by these experts are given in Chapter 7.

For validating survey construct, as explained in Section 5.5.1, t-test was used to validate that lower limit and upper limit of survey responses differ or not. After survey response analysis, t-test was applied according to the explanatory example shown in Section 5.5.1. It was found that
null hypothesis was failed for all the indicators which validates the construct of survey. Next section shows the results for survey reliability test.

5.6.3 Survey Reliability Results
As discussed in Section 5.5.2, SPSS was used for the Cronbach’s Alpha result to perform reliability test. Cronbach’s Alpha value for the survey results was found to be 0.749. Calculations from equation and parameter values are given below;

\[ \alpha = \frac{k}{k - 1} \left(1 - \frac{\sum s_i^2}{s_T^2}\right) \]

Where;
- \( k = 40 \)
- \( \sum s_i^2 = 81.67 \)
- \( s_T^2 = 17.415^2 = 303.28 \)

\[ \alpha = \frac{40}{40 - 1} \left(1 - \frac{81.67}{303.28}\right) \]

\[ \alpha = 0.749 \]

5.6.4 Survey Data Results
The data collected from survey was analyzed according to the methods described in Section 5.5.3. As discussed earlier, the main objective of the survey was to collect ranking and best-practices based on city size. Table 5-13 and Table 5-14 show the results for prioritization and best-practices, respectively.

Besides forming best-practices guidelines for high and low populated cities, the survey results showed some trends which can led to conclusions, given as follows:

1. As shown in Figure 4-2, level of average household income is an important indicator in finalizing the transit stop location. From the survey findings reported in Table 5-14 (indicator number 1.8), it was found that small cities prefer to provide a transit stop in the area having average household income of less than CAD $10,000; whereas, for large
cities, this level goes three time up and reach CAD $32,700. Furthermore, results of Table 5-13 shows that small cities experts consider demographic factors to be of same importance as compared to surrounding land use and accessibility. Whereas, large cities experts consider surrounding land use to be the most important factor followed by accessibility and then demographics at the end. From this, it can be concluded that small cities give more importance to households with less income as compared to large cities. This in turn means that in small cities, transit service is planned to be as a social service, but on the other hand, in large cities, transit is considered as a competitor of private cars.

2. In all the eleven design factors in which the indicator was number of users, Table 5-14 shows that large cities need higher ridership than small cities. Small cities have low densities and therefore, they cannot generate same level of ridership as generated by high population cities. This was one of the deficiencies of past literature and agency manuals that they provide a deterministic value for large and small cities but this survey concludes that small cities required less ridership than large cities for providing the same amenity.

3. From the geographical distribution of responses received, which are shown in Table 5-12, it was found that the responses from experts of large cities were mostly above 10 years of experience, in contrary to response from small cities which were mostly less than 10 years of experience. This concludes about the distribution of transit experts across Canada that highly experience professionals are mostly working in large cities whereas small cities mostly accommodate the relatively young professionals.

The responses received from the survey, given in Table 5-13 and Table 5-14, were further used to form the index tool about transit stop planning. This index tool analyzes the transit stop quantitatively and makes it easier for a transit planner to make decisions.

5.7 Need of Index System for Transit Stop Evaluation

Until now, transit stop planning has subjective nature which largely depends on the transit planners experience aided with some service standards. The subjective nature of the planning process having many factors and indicators involved makes it difficult for the transit planner to make informed decisions. An index based decision support tool can help transit planners to quantitatively evaluate existing stops, improve existing stops by deciding proper location,
spacing and amenities, and allocate new transit stops along street. Location, spacing and design of transit stop, as an index based system, has not been yet considered in the location and transportation engineering problem. Index based studies have increased in fields of water, environment, and transportation engineering field. The major benefit of index based studies is that they can handle many factors in an inter-dependent manner. The degree of loss and damage of resources and capital cost can be reduced if such a system approach to infrastructure planning and management is implemented in which factors are inter-dependent (Khatri et al. 2011). None of the previous work, either mathematical and simulation work, has considered the combined and super-imposed relationship between different transit stop planning factors contributing in an index system. By studying the interaction of all factors on a system or set of systems, decision makers can analyze the overall performance of a system (Isard 1956). Chapter 6 will focus on the transit stop index formation based on results discussed in Section 5.6.3.

5.8 Summary
This chapter reported on the sample and instrument design of expert opinion survey. Analyses of pilot survey findings to enhance the full survey were also discussed. The procedure of validity, reliability tests and survey response data were discussed and at the end final results of benchmarks and prioritization were presented.
<table>
<thead>
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<th>Sr. No.</th>
<th>Category</th>
<th>Indicator</th>
<th>City Category</th>
<th>Coefficient of Variation</th>
<th>Excellent</th>
<th>Acceptable</th>
<th>Unacceptable</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CV (%age)</td>
<td>LL</td>
<td>UL</td>
<td>LL</td>
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<tr>
<td>1.1</td>
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<td>430</td>
<td>554</td>
<td>554</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>400</td>
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<td>547</td>
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<tr>
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<td>Recommended transit stop spacing in Central Business District area of city (CBD), (m)</td>
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<td>138</td>
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<td>Recommended transit stop spacing in sub-urban area of city (m)</td>
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<td>Coefficient of Variation</td>
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<td>Acceptable</td>
<td>Unacceptable</td>
</tr>
<tr>
<td>--------</td>
<td>-----------------------------------------------</td>
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<td>--------------------------</td>
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<td>-------------</td>
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<tr>
<td>2.0</td>
<td>Recommended transit stop spacing in rural area of city (m)</td>
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<td>197</td>
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<td>400</td>
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<td>0</td>
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<td>Overall</td>
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<td>1,070</td>
<td>72</td>
<td>237</td>
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<td>970</td>
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<td>70</td>
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<td>Number of transit users recommended for providing information map at transit stop (No.)</td>
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<td>713</td>
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<td>670</td>
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</tr>
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<td>2.4</td>
<td>Amount of average daily precipitation recommended for providing shelter at transit stop (mm)</td>
<td>Large cities</td>
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<td>5.6</td>
<td>9.4</td>
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<tr>
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<td>Overall</td>
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<td>5.4</td>
<td>2.5</td>
</tr>
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<td>Number of transit users recommended for providing shelter at transit stop (No.)</td>
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<tr>
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<td>Number of weeks of bright sunshine in a year recommended for providing shelter at transit stop (No.)</td>
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<td>87</td>
<td>276</td>
<td>87</td>
<td>0</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>Overall</td>
<td>5.559</td>
<td>160</td>
<td>630</td>
<td>160</td>
<td>0</td>
<td>160</td>
</tr>
<tr>
<td>2.8</td>
<td>Waiting time recommended for providing seats/benches at transit stop (min.)</td>
<td>Large cities</td>
<td>17.16</td>
<td>18</td>
<td>47</td>
<td>8</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Small cities</td>
<td>21.60</td>
<td>25</td>
<td>55</td>
<td>10</td>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Overall</td>
<td>20.41</td>
<td>22</td>
<td>53</td>
<td>10</td>
<td>22</td>
<td>10</td>
</tr>
<tr>
<td>2.9</td>
<td>Recommended stop sign height (m)</td>
<td>Large cities</td>
<td>50.00</td>
<td>3.0</td>
<td>4.5</td>
<td>2.2</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>Small cities</td>
<td>9.260</td>
<td>2.5</td>
<td>3.0</td>
<td>2.0</td>
<td>3.0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Overall</td>
<td>11.05</td>
<td>2.3</td>
<td>4.0</td>
<td>2.0</td>
<td>4.0</td>
<td>0</td>
</tr>
<tr>
<td>2.10</td>
<td>Number of weeks of freezing cold temperature in a year recommended for providing heating system at transit stop (No.)</td>
<td>Large cities</td>
<td>12.47</td>
<td>11</td>
<td>21</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Small cities</td>
<td>21.61</td>
<td>20</td>
<td>25</td>
<td>5</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Overall</td>
<td>13.21</td>
<td>14</td>
<td>26</td>
<td>5</td>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>2.11</td>
<td>Number of transit users recommended for providing heating system at transit stop (No.)</td>
<td>Large cities</td>
<td>6.820</td>
<td>231</td>
<td>500</td>
<td>54</td>
<td>231</td>
</tr>
<tr>
<td></td>
<td>Small cities</td>
<td>12.00</td>
<td>121</td>
<td>550</td>
<td>82</td>
<td>121</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Overall</td>
<td>5.703</td>
<td>190</td>
<td>450</td>
<td>55</td>
<td>190</td>
<td>55</td>
</tr>
<tr>
<td>2.12</td>
<td>Number of transit users recommended for providing Wi-Fi at transit stop (No.)</td>
<td>Large cities</td>
<td>9.530</td>
<td>1,500</td>
<td>2,000</td>
<td>400</td>
<td>1,500</td>
</tr>
<tr>
<td></td>
<td>Small cities</td>
<td>11.70</td>
<td>1,050</td>
<td>570</td>
<td>1,050</td>
<td>0</td>
<td>570</td>
</tr>
<tr>
<td></td>
<td>Overall</td>
<td>9.325</td>
<td>1,370</td>
<td>470</td>
<td>1,370</td>
<td>470</td>
<td>470</td>
</tr>
<tr>
<td>2.13</td>
<td>Number of transit users recommended for providing vending machines at transit stop (No.)</td>
<td>Large cities</td>
<td>6.958</td>
<td>2,800</td>
<td>3,000</td>
<td>400</td>
<td>2,800</td>
</tr>
<tr>
<td></td>
<td>Small cities</td>
<td>5.460</td>
<td>760</td>
<td>310</td>
<td>760</td>
<td>0</td>
<td>310</td>
</tr>
<tr>
<td></td>
<td>Overall</td>
<td>5.980</td>
<td>2,180</td>
<td>390</td>
<td>2,180</td>
<td>390</td>
<td>390</td>
</tr>
<tr>
<td>Sr. No.</td>
<td>Indicator</td>
<td>City Category</td>
<td>Coefficient of Variation</td>
<td>Excellent</td>
<td>Acceptable</td>
<td>Unacceptable</td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>---------------------------------------------------------------------------</td>
<td>--------------------</td>
<td>--------------------------</td>
<td>-----------</td>
<td>------------</td>
<td>--------------</td>
<td></td>
</tr>
<tr>
<td>2.14</td>
<td>Number of transit users recommended for providing ticket machines at transit stop (No.)</td>
<td>Large cities</td>
<td>7.050</td>
<td>960</td>
<td>3,000</td>
<td>220 960</td>
<td>0 220</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Small cities</td>
<td>8.680</td>
<td>527</td>
<td></td>
<td>270 527</td>
<td>0 270</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Overall</td>
<td>7.670</td>
<td>860</td>
<td></td>
<td>250 860</td>
<td>250</td>
</tr>
<tr>
<td>2.15</td>
<td>Recommended width of tactile warning strips (m)</td>
<td>Large cities</td>
<td>21.09</td>
<td>0.7</td>
<td>1.2</td>
<td>0.4 0.7</td>
<td>0 0.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Small cities</td>
<td>24.16</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Overall</td>
<td>21.41</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.16</td>
<td>Recommended width of sidewalk corridor (m)</td>
<td>Large cities</td>
<td>21.58</td>
<td>1.7</td>
<td>4.3</td>
<td>1.2 1.7</td>
<td>0 1.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Small cities</td>
<td>34.073</td>
<td></td>
<td>3.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Overall</td>
<td>21.58</td>
<td></td>
<td>2.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.17</td>
<td>Recommended vertical gap between platform and transit (mm)</td>
<td>Large cities</td>
<td>16.39</td>
<td>0</td>
<td>24</td>
<td>24 80 80</td>
<td>125</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Small cities</td>
<td>13.43</td>
<td></td>
<td>41</td>
<td>41 77 77</td>
<td>113</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Overall</td>
<td>13.35</td>
<td></td>
<td>30</td>
<td>30 80 80</td>
<td>125</td>
</tr>
<tr>
<td>2.18</td>
<td>Recommended horizontal gap between platform and transit (mm)</td>
<td>Large cities</td>
<td>17.97</td>
<td>0</td>
<td>40</td>
<td>40 90 90</td>
<td>150</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Small cities</td>
<td>25.78</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Overall</td>
<td>17.30</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.19</td>
<td>Number of transit users recommended for providing lighting at transit stop (No.)</td>
<td>Large cities</td>
<td>7.629</td>
<td>650</td>
<td>750</td>
<td>120 650</td>
<td>0 120</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Small cities</td>
<td>7.910</td>
<td>180</td>
<td></td>
<td>35 180</td>
<td>0 35</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Overall</td>
<td>5.760</td>
<td>440</td>
<td>85</td>
<td>85 440</td>
<td>85</td>
</tr>
<tr>
<td>2.20</td>
<td>Number of transit users recommended for providing CCTV camera at transit stop (No.)</td>
<td>Large cities</td>
<td>6.280</td>
<td>340</td>
<td>500</td>
<td>60 340</td>
<td>0 60</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Small cities</td>
<td>5.200</td>
<td>206</td>
<td></td>
<td>60 206</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Overall</td>
<td>6.280</td>
<td>340</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

LL = Lower Limit  
UL = Upper Limit
Chapter 6: TRANsit Stop inDEX (TRANSDEX)

6.1 Outline
This chapter deals with the development and application of the Excel-based decision-support tool for transit stop planning. Section 6.2 is about the characteristics of a good model. Section 6.3 describes the three modules of TRANSDEX and Section 6.4 explains the development and interface of TRANSDEX. Section 6.5 is about the applications of TRANSDEX. At the end, Section 6.5 concludes the chapter.

6.2 Characteristics of a Good Model
A good model should have following characteristics to be able to withstand the uncertain conditions in practical phase (Kikuchi and Miljkovic 2001)(Pinto 2010) (Taylor 2006).

1. **Logical Soundness**: the model formulation, input and output should be logically correct and reality based. The inter-dependencies of factors should be demonstrated such that they reflect the practical scenarios. It should take care of cost and human resource.

2. **Practicality**: the model should be practically feasible and easy to understand. Model should be simple so that it can be used by people of all fields in an organization. It should be efficient and should generate results timely. The major drawback of numeric models is that they are not easy sand require special training to use them.

3. **Data Flexibility**: the model should be flexible for modification that if any change is required then it can accommodate it. Changing variables should be easy to handle. During project lifetime, changes are made which requires new evaluation. The model should be flexible enough to handle these evaluations. There should be provisions to add or remove any criteria or constraint and should cover greatest possible range.

4. **Stable and credible output**: the model should be broad enough to apply to several projects. If model is narrow, then it would not be used to compare different projects.

6.3 Modules of TRANSDEX
TRANSDEX is a tri-modular Excel-based decision-support tool composed of the following three modules:

- **VETOP**: eValuate Existing transit sTOPs
- **PETOP**: imProve Existing transit sTOPs
- **NETOP**: allocate NEw transit sTOPs
6.3.1 VETOP - eValuate Existing transit sTOPs

The first module of TRANSDEX, VETOP, is applicable to quantitatively evaluate an existing transit stop. Indicator values for transit stop is mapped on benchmarks to generate an index which range from 0 to 10. An index value of 0 means that the transit stop is performing in its least level of service and an index value of 10 means that the transit stop is performing in its best level of service. In this study, three level of service categories were defined, namely “Excellent”, “Acceptable” and “Unacceptable”. The boundaries of these categories were defined by the user at start of TRANSDEX as shown in Figure 6-1. In addition to fine tuning the results, user also select the city category in which tool is being applied because, as discussed in Chapter 5, benchmarks and priority ranking of small cities are different from those of large cities. The home page of TRANSDEX is given in Figure 6-1 which shows following three things;

- First, user defines the city size in which the tool is being applied.
- Second, user defines the numeric levels of service categories for result representation.
- Third, four steps of fuzzy synthetic evaluation are listed in order of operation.

![TRANSDEX Home Page](image)

Based on user’s numeric levels of service categories, VETOP shows that whether the stop is performing in excellent category, acceptable category, or unacceptable category. The findings of VETOP are further analyzed by PETOP as discussed below.
6.3.2 PETOP - imProve Existing transit sTOPs
First module, VETOP, only evaluate an existing stop and gives it a rating out of 10. However, it did not say anything on how to improve the stop. Therefore, second module, PETOP, was designed which provide recommendations on how the index value of stop can be improved. PETOP results are shown in the form of two charts. First chart shows that how many factors and indicators are in excellent category, acceptable category, and unacceptable category. The user defines the limiting values of these categories, as shown in Figure 6-1. The index value is improved by improving those factors that are of prime importance. Importance of factors are provided by default but user can change them at Step 3 of TRANSDEX. Based on the user’s prioritization, second chart of PETOP is generated with most important factor on left end and least important factor on right end. These charts are further discussed in Section 6.4.4.

6.3.3 NETOP - allocate NEw transit sTOPs
First two modules of TRANSDEX, i.e. VETOP and PETOP analyze the existing transit stops and give improvement recommendations. However, they are not applicable to allocate new transit stops. Therefore, a third module, NETOP, was developed which takes the output of VETOP and input it into an algorithm to allocate new stops. The algorithm starts with initialization in which a lot of stops are placed along the street and VETOP index is calculated. Then one stop with least index is removed and spacing criteria is checked in order to continue or terminate the algorithm. Detailed explanation of NETOP algorithm with case study is given in Section 6.5.2.

6.4 Development of TRANSDEX
6.4.1 Framework Development
As explained in Section 4.3, two main categories were defined in this study – spatial and demographic factors, and design factors. Spatial and demographic factors were sub-divided into two parts; location factors (which relates to positioning of transit stop e.g. walking distance to transit stop, grade of transit stop, type of land-use etc.) and stop spacing factors. Transit stop design is further categorized into four parts. They include the factors related to information provision, passenger comfort, safety, equity, and security. The factor chart is shown in Figure 4-2.
Indicators were grouped after factors, which were directly related to the transit stop planning. These indicators were collected from published articles, transit service planning manuals and then shared with transit experts, as explained in Figure 5.4 – 5.6 in Section 5.3.2. The TRANSDEX interface for framework development is shown in Figure 6-2.

Two filters were applied in this study for customization, as shown in Figure 6-2(b). In the first filter, called “Required in Analysis or Not”, the user choose that if the factor is required in analysis or not. If the user selected “Not Required”, then that factor will not be included in analysis for calculation of final index and all further steps regarding that factor will not be processed. Some factors are also accompanied with the second filter. The factor includes information provision, which include fixed time schedule, real transit position, and information map, heating system, shelter, and seats. These are the factors which may be present at transit stop or not. Depending on its presence at transit stop, calculations are further performed.
(a): Defining Factors/Indicators in TRANSDEX

(b): Filters Applied for Users' Customization

Figure 6.2: TRANSDEX Interface for Framework Development
6.4.2 Benchmarking and Fuzzification of Indicators

Each indicator was benchmarked based on 3 membership functions, i.e. excellent, acceptable and unacceptable; and degree of fuzziness was defined. “Excellent” corresponds to the highest level of service that a transit stop can provide. It refers that the factor has its maximum efficiency at the correspondent stop. “Acceptable” corresponds to the level of service that is lower than its full efficiency but provides an adequate level of service. “Unacceptable” is the level of service that is so poor that it requires an immediate change. The benchmarks of these membership functions are then compared to the field observation to generate the fuzzy sets. In general; triangular or trapezoidal fuzzy sets are used, however in this study; triangular fuzzy sets were developed to plot the membership functions. The two extreme values were kept as user inputs and the middle value was calculated as an average of two extremes (Umer 2015)(Carlsson and Fullér 2000).

Benchmarking is a tool to classify and state the possible development in any transport industry (Deiss 2000). It involves evaluation and recognition of the best-practices for improving the existing system (Spendolini 1992). Benchmarking includes the existing reference points and targets of best-practices that caused future improvement (Kabir and Hasin 2012). For a specific factor, the benchmark of a membership function refers to the degree of its acceptance with regard to that membership function. Benchmarking enhance the possible development by tri-step procedure which include identification of best performance, practices and preparing, and implementing the possible change (Deiss 2000). To compare several systems, the benchmarking should be consistent which serves as the baseline (Sharifi and Murayama 2013). The benchmarking is established based on the limitations of every society and time requirement and is therefore different for different countries and even cities (Debnath et al. 2014). The inter-country performance difference of transport sector shows its potential for improvement. It is more evolved due to development in technology and organizational progress. The change of benchmarking criterions in different countries is highly dependent on growing pressure of economy and transport industry; and public and environmental finances. While benchmarking the transport factors, the important considerations are interaction between two factors; general transport policy and dynamic powers behind the transport demand and supply (Deiss 2000) (Bärlund 2000).
In this study, benchmarking of membership functions was performed through a combination of literature review and expert opinion. The procedure of Khatri et al. (2011) was adopted to define the benchmarks. First, the past literature was consulted to find the guidelines related to indicators. But, complete benchmarking was not available from past literature due to lack of information regarding each indicator and every membership function. Therefore, the information obtained from literature was shared with the transportation experts, in the form of transit expert opinion survey, and benchmarks were obtained. The expert opinion about the benchmarking also differ based on the level of their knowledge and expertise in the respected field. Therefore, the benchmarking of indicators led to uncertainty which aroused from lack of human precision and knowledge.

After defining the benchmarks of membership functions, the degree of fuzziness of each factor was defined. This degree of fuzziness was not available is any literature or manual and was purely based on expert opinion. Degree of fuzziness was expressed in percentage. The membership functions were formed based on degree of fuzziness which was a variable quantity and express the uncertainty related to any indicator. It was formulated as the overlapping characteristic of membership function. As the degree of fuzziness increases, the membership function (of say, acceptable) super-impose itself onto the immediately adjacent membership functions (say, excellent and unacceptable). For example, say, the benchmarks of factor longitudinal slope of pathway were categorized 0% to 3%, 3% to 8% and 8% to 12% for excellent, acceptable and unacceptable respectively. With the degree of fuzziness as 25%, 50%, 75% and 100%, the change of benchmarks is shown in Table 6-1 and the fuzzy membership functions are shown in Figure 6-3 (a), (b), (c) and (d) respectively.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Degree of Fuzziness</th>
<th>Excellent (%)</th>
<th>Acceptable (%)</th>
<th>Not Acceptable (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope of Transit Stop Pathway</td>
<td>25 %</td>
<td>0 to 4.25</td>
<td>2.25 to 9.00</td>
<td>6.75 to 13.00</td>
</tr>
<tr>
<td>(%)</td>
<td>50 %</td>
<td>0 to 5.50</td>
<td>1.50 to 10.00</td>
<td>5.50 to 14.00</td>
</tr>
<tr>
<td></td>
<td>75 %</td>
<td>0 to 6.75</td>
<td>0.75 to 11.00</td>
<td>4.25 to 15.00</td>
</tr>
<tr>
<td></td>
<td>100 %</td>
<td>0 to 8.00</td>
<td>0.00 to 12.00</td>
<td>3.00 to 16.00</td>
</tr>
</tbody>
</table>
(a): Membership functions for 25% degree of fuzziness

(b): Membership functions for 50% degree of fuzziness

(c): Membership functions for 75% degree of fuzziness
In this study, the factors and their benchmarks were collected through literature review and expert opinion. A complete list of factors, their benchmarks, and their degree of fuzziness are given in Table 4-2. Degree of fuzziness was developed by the difference of opinions of experts. Degree of fuzziness is an input quality, as shown in Figure 6-2(a), and the user can change the default value according to one’s experience and knowledge. A typical example for longitudinal slope of pathway is shown in Table 6-2.

### Table 6-2: Benchmarking Membership Functions of Indicator

<table>
<thead>
<tr>
<th>Category</th>
<th>Indicator</th>
<th>Fuzzification</th>
<th>Excellent</th>
<th>Acceptable</th>
<th>Not Acceptable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Slope (%)</td>
<td>Input Values</td>
<td>0</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fuzzified</td>
<td>3</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Values</td>
<td>0</td>
<td>2.4</td>
<td>6.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3.6</td>
<td>9.6</td>
<td>16.8</td>
</tr>
</tbody>
</table>

The benchmarking was performed by entering the values in green; these were termed as input values. These were then overlapped onto the neighboring functions to the extent that degree of fuzziness is entered, to form the fuzzified values. These fuzzified values were then mapped on the universe of discourse to plot the membership functions. The bottom row, in both input and fuzzified inputs, shows the maximum value of membership function and top row exhibits the minimum value of membership function. This is more clearly explained in Figure 6-4.
As shown in Figure 6-4, the membership functions are overlapping with the neighboring ones. This overlapping characteristic of membership functions represents the unclear or fuzzy part of an indicator. This vagueness is due to lack of human precision of knowledge. Fuzzy set theory enables different unit quantities to be represented in same fuzzy set. The Excel interface of TRANSDEX for benchmarking and fuzzification is shown in Figure 6-5 (a), (b), (c), and (d).
## BENCHMARKS

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Variables Factor</th>
<th>Units</th>
<th>Degree of Fuzziness (%age)</th>
<th>Excellent Min</th>
<th>Excellent Max</th>
<th>Satisfactory Min</th>
<th>Satisfactory Max</th>
<th>Un-satisfactory Min</th>
<th>Un-satisfactory Max</th>
<th>Case Study Min</th>
<th>Case Study Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Location of individual transit stop</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1</td>
<td>Accessibility to/from stop</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1.1</td>
<td>Access to stop by walk/Cycle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1.1.1 Access/egress distance to/from street tran</td>
<td>m</td>
<td>18.9</td>
<td>0</td>
<td>430</td>
<td>430</td>
<td>750</td>
<td>750</td>
<td>1000</td>
<td>600</td>
<td>800</td>
<td></td>
</tr>
<tr>
<td>1.1.1.2 Longitudinal slope of sidewalk corridor to</td>
<td>%age</td>
<td>20.64</td>
<td>0</td>
<td>4</td>
<td>4</td>
<td>7</td>
<td>7</td>
<td>10</td>
<td>5</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

(a): Excel Interface of Benchmarking

## FUZZIFICATION OF BENCHMARKS

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Variables Factor</th>
<th>Units</th>
<th>Degree of Fuzziness (%age)</th>
<th>Excellent Min</th>
<th>Excellent Max</th>
<th>Satisfactory Min</th>
<th>Satisfactory Max</th>
<th>Un-satisfactory Min</th>
<th>Un-satisfactory Max</th>
<th>Case Study Min</th>
<th>Case Study Max</th>
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<tbody>
<tr>
<td>1</td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>1.1</td>
<td>Accessibility to/from stop</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1.1</td>
<td>Access to stop by walk/Cycle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1.1.1 Access/egress distance to/from street tran</td>
<td>m</td>
<td>18.9</td>
<td>0.189</td>
<td>430</td>
<td>430</td>
<td>750</td>
<td>750</td>
<td>1000</td>
<td>600</td>
<td>800</td>
<td></td>
</tr>
<tr>
<td>1.1.1.2 Longitudinal slope of sidewalk corridor to</td>
<td>%age</td>
<td>20.64</td>
<td>0.2064</td>
<td>4</td>
<td>4</td>
<td>7</td>
<td>7</td>
<td>10</td>
<td>5</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

(b): Fuzzification of Indicator Benchmarks
### FUZZY GRAPHS

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Variables Attributes</th>
<th>Type of fuzzy sets</th>
<th>Excellent</th>
<th>Satisfactory</th>
<th>Un-satisfactory</th>
<th>Case Study</th>
<th>Cardinality</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Location of individual transit stop</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>1.1</td>
<td>Accessibility to/from stop</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1.1</td>
<td>Accessibility to/from stop by walk/Cycle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1.1.1</td>
<td>Access/progress distance to/from the stop</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**SPATIAL AND SOCIODEMOGRAPHIC FACTORS**

- **Benchmarks**
  - 0
  - 245.24
  - 490.48
  - 346.73
  - 572.99
  - 797.25
  - 480.32
  - 868.385
  - 1047.25

- **Ranges**
  - 0
  - 1
  - 0
  - 0
  - 1
  - 0

- **Original**
  - 0
  - 0
  - 0

![Graph](c): Generation of Fuzzy Graphs
### Fuzzy Sets

<table>
<thead>
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<th>Sr. No.</th>
<th>Factor and Indicator</th>
<th>Weights</th>
<th>Type of fuzzy sets</th>
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<th>Satisfactory</th>
<th>Un-satisfactory</th>
<th>Case Study</th>
<th>Cardinality</th>
</tr>
</thead>
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<td></td>
<td>0.260252466</td>
<td>0.260252466</td>
<td>0.56098444</td>
<td>0.13203664</td>
<td>1</td>
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<tr>
<td>1.1</td>
<td>Accessibility to/from stop</td>
<td>0.32</td>
<td></td>
<td>0.121035175</td>
<td>0.121035175</td>
<td>0.363475604</td>
<td>0.665017934</td>
<td>1</td>
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<tr>
<td>1.1.1</td>
<td>Access to stop by walk/Cycle</td>
<td>0.69</td>
<td></td>
<td>0.24524</td>
<td>0.49048</td>
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<td>0.78725</td>
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<tr>
<td>1.1.1.1</td>
<td>Access express distance to/from the stop</td>
<td>0.69</td>
<td>Benchmarks</td>
<td>0</td>
<td>245.24</td>
<td>490.48</td>
<td>348.73</td>
<td>572.99</td>
</tr>
<tr>
<td></td>
<td>Ranges</td>
<td></td>
<td></td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Original</td>
<td></td>
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<td>0</td>
<td>0.67015944</td>
<td>0</td>
<td>0</td>
<td>0.67015944</td>
</tr>
<tr>
<td></td>
<td>Normalized</td>
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<td></td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1.1.1.2</td>
<td>Longitudinal slope of sidewalk to/from the stop</td>
<td>0.31</td>
<td>Benchmarks</td>
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<td>2.3956</td>
<td>6.4192</td>
<td>3.1744</td>
<td>5.3968</td>
</tr>
<tr>
<td></td>
<td>Ranges</td>
<td></td>
<td></td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
|         | Original                    |         |                    | 0          | 0.821454284 | 0            | 0          | 0.821454284 | 0          | 0          | 0.821454284 | 1

(d): Generation of Fuzzy Sets and Normalized Fuzzy Sets

Figure 6-5: TRANSDEX Interface for Benchmarking and Fuzzy Calculations
6.4.3 Prioritization and Aggregation

In many fuzzy set theory applications such as pattern recognition, MCDM, diagnostic and fuzzy logic control; the weighted aggregation is always a problem (Dyck et al. 2014). As discussed in Section 2.6, SAW and AHP has gained much importance in research work. However, due to some limitations of AHP, some modifications have been proposed by different researchers. All these modifications are based on different axioms and give different weights which ultimately change the overall index. Different MCDM techniques yield different results under same condition and same input (Gershon and Duckstein 1983). Almost 40% of time, one technique gives different result from other (Voogd 1983). This inconsistency is due to different weight calculation method, different algorithm and axioms, scaling the objectives and adding new parameter (Zanakis et al. 1998). The difference in results are also due to limited sample size (Zanakis et al. 1998), information gathering procedure (Olson et al. 1995), comparison intentions, (Kok 1986) and human implementation error (Hobbs, Chankong, and Hamadeh 1992). Therefore, it is not possible to declare one method suitable than other, or to find the reason for weight difference between several methods (Zanakis et al. 1998). However, in this study, one method was selected and applied to determine the prioritization among factors in step 3 of TRANSDEX, as discussed in Section 2.5.4.3. That method was selected which satisfy the following two criterions:

- Gives minimum error
- Gives minimum number of pairwise comparisons

From the comprehensive list of 34 factors, as discussed in Section 4.3, 4 Level-2 factors from design criteria were chosen to perform the multi-criteria analysis. The 4 factors chosen for this study were;
1. Information provision (IP)
2. Passenger comfort (PC)
3. Equity and safety from accidents (ES)
4. Security from crime (S)

The six MCDM methods discussed in Section 2.6 were applied to the above stated 4 factors and the results are shown in Figure 6-6 below.
Considering the wide use of Saaty’s AHP in decision-making problems, it was considered as baseline in this study. Procedure adopted to select the most optimal method is described below:

- Determine the root mean square error (RMSE) for each method
- Determine weighted RMSE for each method
- Determine weighted pair wise comparison error

**Step No. 1**
The degree of deviation of relative weights was analyzed by Root Mean Square Error (RMSE) (Sangwook Lee 2014). RMSE can be found by Equation 6-1.

\[
RMSE = \sqrt{\frac{\sum_{i=1}^{n}(X_i - X_i')^2}{n}}
\]  
Equation (6-1)

Where:
- \( X_i \) = Weight by modified AHP
- \( X_i' \) = Weight by traditional AHP
- \( n \) = Number of factors in Matrix = 4

RMSE was calculated for every factor in each of modified AHP method. Figure 6-7 shows the result of RMSE.
Step No. 2
To find the relative importance of each method at each factor, the RMSE of individual factor of each method was multiplied with the relative weights obtained by respective factor of that method. The results show that ANC-AHP, SAW, and BR-AHP have very little deviation from AHP proposed by Saaty. The deviations showed by these methods were 0.025%, 0.025% and 2.205% respectively. However, the deviations of F-AHP and IM-AHP were 20.679% and 103.468% respectively. These results are shown in Figure 6-8. So, the most practical method was found based on ANC-AHP, SAW, and BR-AHP represented in form of practicability analysis.
Step No. 3

In practice, experts try to use that method which is less time consuming and easy to understand. If the result shows a little deviation but the number of comparisons is reduced, it would be more applicable on industrial scale. Therefore, for practicability analysis, the RMSE was aggregated by the number of pair-wise comparison required for SAW and ANC-AHP to form weighted RMSE and is given below in Figure 6-9.

The number of pair wise comparisons required by each method is represented by Equation 6-2.

\[
SAW \ & \ ANC - AHP = \frac{m}{2} (n^2 - n + m - 1)
\]

Equation (6-2)

Where;

- \( n \) = number of alternatives
- \( m \) = number of criterions

![Figure 6-9: Weighted Pairwise Comparison Error](image)

On the basis of practicability analysis, it is inferred that for factors less than 5, SAW and ANC-AHP yields better results than all others. In the hierarchical chart used in this study, maximum number of factors in any category is less than 5. Therefore, according to Figure 6-9, ANC-AHP yields the results which are closest to AHP. Because the number of comparisons, for a given number of factors, in ANC-AHP is same as in AHP, therefore, AHP
was used to develop the index. Figure 6-10 shows the TRANSDEX interface for prioritization.

![TRANSDEX Interface for Prioritization](image)

Two dropdown lists were provided for input from user. The first dropdown was the intensity of importance of first factor over second factor whereas; the second dropdown was the ranking of first factor over second factor. The possible combinations are shown in Figure 6-11.

![Possible Combinations for Prioritization](image)

### 6.4.4 Defuzzification and Result Generation

For defuzzification, scoring method was used. As explained in Section 6.3, TRANSDEX was a tri-modular tool. Result for VETOP was shown in the form of a “meter rating” index, as shown in Figure 6-12(a). Result of PETOP was shown in the form of “factor rating” and “factor importance” charts, as shown in Figure 6-12(b) and Figure 6-12(c), respectively. PETOP chart – 1, shown in Figure 6-12(b), arrange the factors and indicators according to their index values which helps to differentiate those factors which are causing a low VETOP rating. To improve the VETOP index, PETOP chart – 2, shown in Figure 6-12(c), arrange factors in their priority order as defined at Step 3 of TRANSDEX. Right factors shown in cyan color are those which are of top importance and a decrease in index values of these factors cause considerable impact on the VETOP “meter rating”. Left most are the least important factors having least impact on VETOP “meter rating” index.
Figure (a): Output for VETOP – “Meter-Rating”
Figure (b): Output (1) for PETOP – “Factor Rating” Chart
**Figure (c): Output (2) for PETOP – “Factor Importance” Chart**

**Figure 6-12: TRANSDEX Interface for Result Generation**
In factor rating chart shown in Figure 6-12(b), green area corresponds to those factors and indicators which are at their best level. Orange area corresponds to those factors and indicators which are at their acceptable level and can be improved. Red area corresponds to those factors and indicators which needs special consideration and immediate improvement. The horizontal red line corresponds to the maximum level of unacceptable category and minimum level of acceptable category. Similarly, horizontal orange line corresponds to the maximum level of acceptable category and minimum level of excellent category and horizontal green level corresponds to the maximum level of excellent category. These horizontal lines correspond to the level of service which is also an input quantity from the user and is entered at start of the TRANSDEX as shown in Figure 6 – 1. The developed tool was applied to 2 case studies which are explained in next section.

6.5 Applications of TRANSDEX
The TRANSDEX tool developed using fuzzy synthetic evaluation and survey responses was applied in two concepts;
1. To evaluate and improve existing transit stops using VETOP and PETOP
2. To allocate new transit stops using NETOP

These two concepts along with examples are explained below.

6.5.1 Case Study – 1: Analyzing Existing Transit Stops Using VETOP and PETOP
For analyzing individual transit stops, two transit stops were selected, one having basic infrastructure and other having advanced infrastructure. The details are given as under.

6.5.1.1 Case Study – 1(a): Analyzing Basic Transit Stop
6.5.1.1.1 Location of Stop
For analyzing basic transit stop using VETOP and PETOP modules of TRANSDEX, a transit stop was picked randomly inside City of Kelowna, BC, as shown in Figure 6-13. City of Kelowna is on the edge of small and medium size cities, having a population of 127,380 in 2016 (Statistics-Canada 2017). City of Kelowna is ranked 43 on national population list and is divided into 9 sectors and 28 sub-sectors. For traffic analyses purpose, City of Kelowna is divided into 184 zones. The details about the selected transit stop are given in next section.
(a): Location of Transit Stop Selected for Evaluation with Basic Infrastructure

(b): Amenities at Transit Stop Selected for Evaluation with Basic Infrastructure

Figure 6-13: Transit Stop Selected for Evaluation with Basic Infrastructure
6.5.1.1.2 Indicator Values for Stop

Kelowna is a having a population of 127,380. Therefore, the benchmarks for small cities, shown in Table 5-14, were applicable on this stop. Selected stop was a minor stop with very basic infrastructure as shown in Figure 6-13(b). Bike-and ride or park-and ride facilities was not provided. Further, no information provision was provided at stop. From basic amenities, seats, garbage receptacle, and stop sign were provided but shelter was not provided and consequently it means that heating system was also not provided at this transit stop. In addition, none of enhanced amenities were provided which include Wi-Fi, vending machine, or ticket machine. Taking equity into consideration, surface marking was also absent from this transit stop, however, side walk, vertical gap, and horizontal gap were considered for appropriate access/egress of wheelchairs. Furthermore, none of security feature was provided (which include stop light and CCTV Camera). The indicator value for this particular stop is given in Table 6-3 below.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Indicator</th>
<th>Field Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Walking distance for passengers for accessing/egressing transit (m)</td>
<td>149 to 565</td>
</tr>
<tr>
<td>2</td>
<td>Longitudinal grade (%age)</td>
<td>2 to 3</td>
</tr>
<tr>
<td>3</td>
<td>Driving transit user (No.)</td>
<td>Not Required</td>
</tr>
<tr>
<td>4</td>
<td>Residential units in stop catchment area (No.)</td>
<td>1272</td>
</tr>
<tr>
<td>5</td>
<td>Employment number in stop catchment area (No.)</td>
<td>713</td>
</tr>
<tr>
<td>6</td>
<td>Commercial land area in stop catchment area (sq.ft.)</td>
<td>Not Required</td>
</tr>
<tr>
<td>7</td>
<td>School enrolment in stop catchment area (No.)</td>
<td>224</td>
</tr>
<tr>
<td>8</td>
<td>Average income of people (CAD$)</td>
<td>44,787</td>
</tr>
<tr>
<td>9</td>
<td>Percentage of elderly people in catchment (%age)</td>
<td>17</td>
</tr>
<tr>
<td>10</td>
<td>Percentage of juniors in catchment (%age)</td>
<td>28</td>
</tr>
<tr>
<td>11</td>
<td>Stop spacing (m)</td>
<td>456</td>
</tr>
<tr>
<td>12</td>
<td>Daily transit users (No.)</td>
<td>70</td>
</tr>
<tr>
<td>13</td>
<td>Average daily precipitation (mm)</td>
<td>0 to 24.9</td>
</tr>
<tr>
<td>14</td>
<td>Weeks of bright sunshine in a year (No.)</td>
<td>23</td>
</tr>
<tr>
<td>15</td>
<td>Waiting time of transit users (min.)</td>
<td>5 to 30</td>
</tr>
<tr>
<td>16</td>
<td>Stop sign height (m)</td>
<td>2 to 2.5</td>
</tr>
<tr>
<td>17</td>
<td>Weeks of extreme cold in a year (No.)</td>
<td>9</td>
</tr>
<tr>
<td>18</td>
<td>Width of tactile warning strips (m)</td>
<td>0</td>
</tr>
<tr>
<td>19</td>
<td>Width of sidewalk corridor (m)</td>
<td>1 to 1.2</td>
</tr>
<tr>
<td>20</td>
<td>Vertical gap (mm)</td>
<td>0 to 70</td>
</tr>
<tr>
<td>21</td>
<td>Horizontal gap (mm)</td>
<td>0 to 100</td>
</tr>
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</table>
Traditionally, to calculate walking distance, only half distance of two consecutive stops were used which are placed on same line. In other words, only parallel distance is considered in determining walking distance and perpendicular distance is ignored. However, in practical scenario, perpendicular distance is also of same importance as the parallel distance. Therefore, walking distance used in this study was half of the distance between the stop under consideration and its nearest stops so that they made a circle with center at the stop being considered. This was not a single value but a range of values, because the distances between the stops were not constant, as shown in Figure 6-14. In other words, minimum and maximum distance measured from the stop to the boundary and its catchment area (shown in black) was considered as the accessible walking distance. As explained earlier, the tool developed is flexible to handle a constant value from field or a value having a maximum and minimum value (range value).

![Figure 6-14: Stop Circle for Calculating Walking Distance (Stop Catchment Area)](image)

Longitudinal grade of sidewalk was calculated using ArcGIS V10.4.1. Two shapefiles were collected from City of Kelowna website (City of Kelowna 2017), DEM2015_Lines and DEM2015_Points. Slope was calculated from DEM files using Triangular Irregular Network (TIN). The DEM2015_Lines and DEM2015_Points were first converted to TIN using “Create TIN 3D Analyst”. This TIN file was then converted into raster using “TIN to Raster
3D Analyst”. That raster file was then used to find final slope of City of Kelowna through spatial analyst extension > surface > slope. Socio-economic indicators, including number of residential units, average income of people, and percentage of elders and minor were collected from the Okanagan household travel survey. This stop only serves route number 10. Data for daily transit users were collected from BC Transit. Average daily precipitation, prevailing temperatures in summer and winter were obtained from Government of Canada website (Government of Canada 2017). Stop sign height, width of sidewalk corridor, vertical gap and horizontal gap were measured physically at the stop. The results obtained from TRANSDEXX are reported in next section.

6.5.1.1.3 Results and Discussion

From the benchmarks for small cities, as given above in Table 5-13 and Table 5-14, and the field conditions in Table 6-3, results are shown in Figure 6-15. Figure 6-15(a) shows overall performance of transit stop using VETOP “meter-rating”, Figure 6-15(b) shows the individual rating of every factor using PETOP “factor-rating” and Figure 6-15(c) shows the factors which are weighted higher to improve the overall index using PETOP “factor-importance”. Result from VETOP shows that the stop performance is at lower limit of excellent level whereas result from PETOP given in Figure 6-15(b) shows the factors which cause this lower level. From the Figure 6-15(b), 15 factors and indicators lie in the range of excellent level, 16 factors and indicators lie in the range of acceptable level and 4 factors lie in range of unacceptable level, therefore, to improve the stop performance, major consideration should be given to those factors which are in unacceptable level and performing least. These are shown in PETOP chart-2 given in Figure 6-15 (c). Among unacceptable factors, two factors were from design criteria and two factors were from spatial and demographics criteria. Two factors from design criteria included tactile warning strips and sidewalk corridor. Tactile warning strips were absent from the stop and according to benchmarks for small cities defined in Table 5-14, there must be at least 0.4m of tactile warning strips at every transit stop, however, more than 0.7m are preferred. Similarly, sidewalk corridor provided was less than what is given in Table 5-14. From the two factors of spatial and demographics criteria, one factor was from Level – 3 and other factor was from Level – 2. Level – 2 factor was the demographics within the catchment area. Under demographics, three factors were arranged, as shown in Figure 4-2. These 3 factors included income, percentage of junior and percentage of senior. Among these three factors, percentage
of junior and percentage of senior was performing under acceptable level but income was performing under unacceptable level. This means that the income of residents there were too high as compared to the benchmarks developed in Table 5-14. Another important conclusion drawn from this example is that it is not necessary that a basic transit stop is always performing in worst situation. As in this case, a very basic stop is performing in an excellent range because of the strong land use and appropriate stop spacing.

(a): Result for Case Study – 1a – VETOP “meter-rating”
(b) Result for Case Study - 1a – PETOP Chart 1 “Factor Rating”
Figures 6-15: TRANSDEX Results for Case Study – 1(a)
6.5.1.2 Case Study – 1(b): Analyzing Advanced Transit Stop

6.5.1.2.1 Location of Stop

For analyzing an advanced transit stop, the transit exchange of UBC (Okanagan campus) was selected as shown in Figure 6-16. UBC (Okanagan campus) is in Kelowna, BC which is a small city. Therefore, the benchmarks and priority weights determined for small cities were used. The indicator values for this stop are given in following section.

(a): Location of Transit Stop Selected for Evaluation with Advanced Infrastructure
6.5.1.2.2 Indicator Values for Stop

This transit stop serves only The University of British Columbia which is located at the hill top. The stop is located inside university premises which effectively make the walking distance equal to zero. This is a multi-use catchment area having student residences, student enrollment and faculty/staff (as employees). No family residence or commercial area is located near this stop and therefore, demographics factors (which include income, minors, and senior) were also not required in the analysis. Driving transit users were also not included in the analysis because of no residential locality near-by. The remaining indicator values are given in Table 6-4.

Three of the design factors were also omitted from the analysis which were vending machine, ticket machines, and stop light. UBC student union and BC Transit has an agreement for bus passes for all of the UBC students and therefore, ticket machine was not required at this stop. Similarly, university has several cafes near the stop which makes vending machine useless. The city government and university maintain sufficient lighting at the stop during night time; therefore, stop light was also excluded from analysis.
Table 6-4: Indicator Values for Stop Evaluation Having Advanced Infrastructure

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Indicator</th>
<th>Field Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Walking distance for passengers for accessing/egressing transit (m)</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Longitudinal grade (%age)</td>
<td>1.04</td>
</tr>
<tr>
<td>3</td>
<td>Driving transit user (No.)</td>
<td>Not Required</td>
</tr>
<tr>
<td>4</td>
<td>Residential units in stop catchment area (No.)</td>
<td>1700</td>
</tr>
<tr>
<td>5</td>
<td>Employment number in stop catchment area (No.)</td>
<td>1100</td>
</tr>
<tr>
<td>6</td>
<td>Commercial land area in stop catchment area (sq.ft.)</td>
<td>Not Required</td>
</tr>
<tr>
<td>7</td>
<td>School enrolment in stop catchment area (No.)</td>
<td>8388</td>
</tr>
<tr>
<td>8</td>
<td>Average income of people (CAD$)</td>
<td>Not Required</td>
</tr>
<tr>
<td>9</td>
<td>Percentage of elderly people in catchment (%age)</td>
<td>Not Required</td>
</tr>
<tr>
<td>10</td>
<td>Percentage of juniors in catchment (%age)</td>
<td>Not Required</td>
</tr>
<tr>
<td>11</td>
<td>Stop spacing (m)</td>
<td>Not Required</td>
</tr>
<tr>
<td>12</td>
<td>Daily transit users (No.)</td>
<td>5107</td>
</tr>
<tr>
<td>13</td>
<td>Average daily precipitation (mm)</td>
<td>0 to 24.9</td>
</tr>
<tr>
<td>14</td>
<td>Weeks of bright sunshine in a year (No.)</td>
<td>23</td>
</tr>
<tr>
<td>15</td>
<td>Waiting time of transit users (min.)</td>
<td>5 to 15</td>
</tr>
<tr>
<td>16</td>
<td>Stop sign height (m)</td>
<td>2 to 2.5</td>
</tr>
<tr>
<td>17</td>
<td>Weeks of extreme cold in a year (No.)</td>
<td>9</td>
</tr>
<tr>
<td>18</td>
<td>Width of tactile warning strips (m)</td>
<td>0</td>
</tr>
<tr>
<td>19</td>
<td>Width of sidewalk corridor (m)</td>
<td>2.5 to 3.0</td>
</tr>
<tr>
<td>20</td>
<td>Vertical gap (mm)</td>
<td>0 to 50</td>
</tr>
<tr>
<td>21</td>
<td>Horizontal gap (mm)</td>
<td>0 to 25</td>
</tr>
</tbody>
</table>

6.5.1.2.3 Results and Discussion

The final results of TRANSDEX is shown in Figure 6-17. VETOP result of Figure 6-17(a) shows an index value of 9.23 out of 10 which lie in excellent level. However, PETOP chart 1 of Figure 6-17(b) shows that there were some factors which are performing in unacceptable level. As shown in Figure 6-17(b), this transit stop has a score of 10 in location criteria and a score of 8.1 in design criteria. Three factors from design criteria fall under unacceptable level. The benchmarks of Table 5-14 show that if the ridership increases from 206 for a small city, CCTV camera should be provided. But at this stop, ridership was more than 5000 a day and yet no CCTC camera was provided. Same goes for Wi-Fi facility and tactile warning strips. If the tactile warning strip of 1.2 meter was provided besides Wi-Fi and CCTV camera, then overall score of this stop could be increased to 10.00. Most important factor, as suggested by PETOP chart 2 of Figure 6-17(c), is CCTV camera followed by tactile warning strips and Wi-Fi.
(a): Result for Case Study – 1b – VETOP “meter-rating”
144

(b): Result for Case Study – 1b – PETOP Chart 1 “Factor Rating”
Figure 6-17: TRANSDEX Results for Case Study – 1(b)
6.5.2 Case Study – 2: Allocating New Transit Stop Using NETOP

6.5.2.1 Location of Street

Case study 1 shows the application of VETOP and PETOP. Case study 2 deals with the application of NETOP for allocating new transit stop on a street. Transit stop allocation is a complex task consisting of both quantitative and qualitative criterions. Quantitative criterions are easy to measure; however, qualitative criterions are subjective and depend on the expert or planner. The major objectives of transit stop allocation are to;

- Achieve minimum passenger travel time i.e. maintain the suitable spacing between stops.
- Provide maximum area coverage i.e. maximum walk access, bike-and-ride facility, park-and-ride facility etc.
- Attract maximum passengers to improve ridership i.e. super impose above two objectives.
- Serve major centers and activity points i.e. location of transit stop should be appropriate.
- Achieve minimum system cost i.e. design the transit stop accordingly.
- Meet the relationship goals of land use, economic development, and population needs.

All the allocation objectives conflict with each other. For example, closer stops can give more access to passengers but increase the on-line travel time. Similarly, if stops are wide spread, they can increase the on-line travel time but decrease the passenger access. Therefore, the multi-objective allocation tool developed in this study was applied to solve transit stop allocation problem.

For traffic analysis purpose, City of Kelowna is divided into 184 traffic zones. Out of these 184 traffic analysis zones, 35 zones lie in sector number 4 which is the densest sector in City of Kelowna with a stop density of 13.86 stops/sq.km. For transit stop allocation, a random street, Ethel Street, was chosen in sector number 4. This is one of the longest streets that cross the Harvey Avenue and connects both sides of downtown, spanning at a length of almost 3.75 km. Currently, 7 transit stops serve this street at stop spacing of 211m, 586m, 726m, 383m, 988m and 196m as shown in Figure 6-18(a).
6.5.2.2 Indicator Values for Street

For transit stop allocation, only spatial and demographic factors were considered and design factors were removed from the analysis. Ethel street is in central business district area; therefore, park-and-ride facility was also ignored from the analysis. The slope of road
remains same throughout its length which is less than 1.66%, calculated using ArcGIS 10.4.1. According to benchmarks defined in Table 5-14, up to 4% slope is allowed. Therefore, the slope factor was also ignored from the analysis because this indicator effect equally to all the stops. Ignoring these two factors makes accessibility dependent only on one indicator – access or egress distance. The average income of street catchment area lies between CAD $35,000 to CAD $55,000 which is above the benchmarks defined in Table 5-14 and effect all stops equally. Therefore, this indicator was also removed from the analysis. As this street is in the downtown area, therefore the spacing benchmarks for central business district were used. The surrounding land use area is a mixed land use having residential apartments, commercial land development and employment centers. Demographic details of the street were collected from City of Kelowna’s website. The indicator values and TRANSDEX values obtained for the current configuration (Figure 6-18-a) are shown in Table 6-5(a).

6.5.2.3 Stop Allocation and Discussion

The conventional approach of stop elimination was adopted in this study. First, an infinite number of stops were placed and then those stops were removed which show minimum index value. The algorithm adopted in this study for stop allocation is shown in Figure 6-19 and is discussed below.

**Step No. 1:**
Initialize the algorithm with locating a large number of stops. These stops are called unlabelled stops. Spacing between these stops depends on the accuracy of software being used for stop allocation. However, the initial spacing can not exceed the “acceptable” criteria as defined in Table 5-14. Figure 6-18(b) shows initial stops located nearly at 200m distance.

**Step No. 2:**
Mark the two terminal stops as fix stops. These fixed stops are called labelled stops. Terminal stops are marked labelled stops because a transit service is planned to start and end at some high-demand areas, for example downtown or shopping mall. If these stops are removed as a result of analysis, then service will no longer serve high demand areas and would not be much beneficial. If “n” unlabelled stops were first allocated in Step # 1, then after removing 2 labelled stop from analysis, remaining unlabelled stops will be “n-2”.

148
Step No. 3:
Calculate the index value for all stops using VETOP module of TRANSDEX. As described in Section 6.4.1, TRANSDEX gives user option to select from the factors presented. In NETOP application spacing factor is excluded from the analysis because spacing constraint is applied externally in Step # 5 of algorithm. For calculating index value at initial stages, catchment area of stop is considered to be 400m buffer instead of half-length between stops. However, as the distance between stops is increased in subsequent iterations, catchment area changes from 400m buffer to half-length between stops. The VETOP value for case study is shown in Table 6-5(b).

Step No. 4:
Depending on the VETOP values of TRANSDEX, remove the stop having least index value. TRANSDEX calculate the index value based on a set of factors considering their interdependencies. Benchmarks and priority order set at Step 2 and Step 3 of TRANSDEX are used to calculate the index and least index value means that the catchment area of stop is so weak that it did not require a stop. Hence, least index value stop is removed, say “k-th” stop, out of “n-2” stops.

Step No. 5:
After removing the “k-th” stop from further analysis, the interspacing between “k-1-th” stop and “k+1-th” is checked according to criteria defined in Table 5-14. If the interspacing between two stops meets the criteria, then proceed with the algorithm. Else, if the interspacing does not meet the criteria, then “k-th” stop is returned back and also marked as “labelled” stop. This labelled stop, just as terminal stops at Step #2, will not be open for any further analysis.

Step No. 6:
After removing “k-th” stop from analysis, recalculate the index value for “k-1-th” stop and “k+1-th” stop. Index values of only these two stops are expected to be changed because by removing “k-th” stop, catchment area of these two stops are enlarged.

Step No. 7:
Iterations are put to every stop and when number of iterations become equal to number of unlabelled stops, as calculated at Step #2, algorithm is stopped. The final results of case study is shown in Figure 6-18(c) and their VETOP values are shown in Table 6-5 (c).
Initialization: Locate a large number of unlabeled stops (say, “n” stops)

Mark the two terminals as labelled stops to end up with “n-2” unlabelled stops

Calculate the index value for all stops

Remove the unlabelled stop with the lowest index value (say, k-th stop)

Is the interspacing between stop “k-1” and stop “k+1” within the acceptable spacing range?

NO

Return back stop “k” and mark it as labelled

YES

Recalculate the index value for stop “k-1” and stop “k+1”

Is i = n-2?

YES

STOP

NO

START (i=0)

STOP Allocation Approach

Figure 6-19: Framework for NETOP
<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Category</th>
<th>Indicator</th>
<th>(a) TRANSDEX Value for Previous (Current) Stop Configuration</th>
<th>(c) TRANSDEX Value for New Stop Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Description</td>
<td>Unit</td>
</tr>
<tr>
<td>1.1</td>
<td>Spatial and Demographic Indicators</td>
<td>Walking distance for pedestrians</td>
<td>m</td>
<td>103 - 730</td>
</tr>
<tr>
<td>1.2</td>
<td>Residential units in catchment area</td>
<td>No.</td>
<td>334</td>
<td>1005</td>
</tr>
<tr>
<td>1.3</td>
<td>Employees in catchment area</td>
<td>No.</td>
<td>1262</td>
<td>769</td>
</tr>
<tr>
<td>1.4</td>
<td>Commercial land in catchment area</td>
<td>sq. ft.</td>
<td>1268770</td>
<td>149807</td>
</tr>
<tr>
<td>1.5</td>
<td>School enrolment in catchment area</td>
<td>No.</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1.6</td>
<td>Elders in catchment area</td>
<td>%</td>
<td>27.9</td>
<td>27.9</td>
</tr>
<tr>
<td>1.7</td>
<td>Minors in catchment area</td>
<td>%</td>
<td>7.70</td>
<td>7.8</td>
</tr>
<tr>
<td>1.8</td>
<td>Stop spacing</td>
<td>m</td>
<td>211</td>
<td>585</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Category</th>
<th>Indicator</th>
<th>(b) TRANSDEX Values for Stops Located @ Approximately 200m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Description</td>
</tr>
<tr>
<td>1.2</td>
<td>Residential units in catchment area</td>
<td>No.</td>
<td>169.3</td>
</tr>
<tr>
<td>1.3</td>
<td>Employees in catchment area</td>
<td>No.</td>
<td>207.19</td>
</tr>
<tr>
<td>1.4</td>
<td>Commercial land in catchment area</td>
<td>sq. ft.</td>
<td>379270</td>
</tr>
<tr>
<td>1.5</td>
<td>School enrolment in catchment area</td>
<td>No.</td>
<td>0</td>
</tr>
<tr>
<td>1.6</td>
<td>Elders in catchment area</td>
<td>%</td>
<td>14.4</td>
</tr>
<tr>
<td>1.7</td>
<td>Minors in catchment area</td>
<td>%</td>
<td>17.0</td>
</tr>
</tbody>
</table>

Spatial and Demographic Index
6.6 Summary

This chapter presented the index-based decision-support tool, its development and its application. The developed tool operates on three basic steps: framework generation and benchmarking; prioritization; and result generation and result analysis. This chapter also showed the application of developed tool for evaluation of existing stops, allocation of new stops and decision-making on amenities.
Chapter 7: Conclusions, Contributions, and Future Recommendations

7.1 Conclusions and Contributions

Public transit systems provide economic, social, and environmental benefits to urban communities through connecting people to destinations, alleviating traffic congestion, and reducing emissions. As such, promoting public transit is an important sustainable community building consideration of modern cities. Being the first points of contact between passengers and the transit service, the location, interspacing, and design of transit stops highly affect passengers’ satisfaction.

This research is concerned with studying the effect of street transit (e.g. bus and streetcar) stop-related factors on transit demand attraction. By reviewing the literature and consulting with transit experts, key stop-related factors that influence passengers’ perception of the service, categorized into three groups (spatial, demographic, and design factors), were identified along with their recommended standards (operations-related factors were not considered in this study).

The literature review and transit experts consultation showed that current transit planning manuals and guidelines suffer from the following limitations: (a) they are silent regarding the relative importance of stop-related factors; (b) they exhibit great deal of variability in service planning standards; and (c) they fail to provide specific standards for different city sizes.

To date, the transit stop planning process is subjective and largely depends on the transit planner’s experience aided with some service standards. Such subjective nature, coupled with the number of factors involved, inculcates uncertainties making it difficult for the transit planner to make informed decisions. In addition, the location, spacing and design of transit stops, in a combined form, has not been properly investigated. None of the previous work, either mathematical or simulation modelling, has considered the super-imposed relationship between different transit stop planning factors. By studying the interaction of all factors on a system or set of systems, decision makers can analyze the overall performance of a system. Furthermore, in spite of dealing with uncertainties in both long-run and short-run decision in transit planning; analysts, planners, and decision-makers do not explicitly consider uncertainties in transit stop
planning. There is no systematic framework available which can identify, categorize, and analyze uncertainties in major transit stop decisions.

To address the above issues, this research adopted a twofold approach. First, an expert opinion survey was conducted among a panel of transit experts across Canada to (a) understand the relative importance of various transit stop-related factors with respect to their attractiveness to passengers; and (b) collect best-practices used in the transit industry to select typical standards for those factors identified in (a). A total of 111 complete observations were collected and classified into two major groups according to city size, namely, small cities and large cities. The collected dataset showed that, among all spatial (i.e. stop location and interspacing) factors, land use is the most important factor that influences demand attraction. On the other hand, the most important design factor that influences demand attraction is real-time information provision. Furthermore, the results showed that the recommended service planning standards for small cities differ from those of large cities. For example, the dataset showed that the required passenger demand to provide a particular amenity (e.g. seat, shelter, or CCTV camera) at the stop in small cities is lower than that required to provide the same amenity in large cities. Variation in experts’ responses for the best-practices was also recorded. Such variation was due to the subjective nature of the problem in question and the uncertainties associated with the transit stop planning that make it difficult to agree on one typical value for a given factor/indicators.

Second, a tri-modular index-based decision-support tool (TRANSDEX: TRANsit Stop inDEX) was developed through the solicitation and synthesis of experts’ opinions using Analytical Hierarchical Process (AHP) and Fuzzy Synthetic Evaluation (FSE). TRANSDEX is an Excel-based tool that provides a simple way to quantitatively evaluate transit stops, based on a single score (or rating index) that ranges from 0 to 10, considering various factors that affect transit ridership. TRANSDEX is intended to help transit planners make informed decisions regarding the location, interspacing, and design of existing/new street transit stops using its three modules: VETOP, PETOP, and NETOP that deal with eValuating Existing transit sTOPs, imProving Existing transit sTOPs, and allocating NEw transit sTOPs, respectively.
The collected survey responses also facilitated to strengthen the hypothesis that best-practices cannot be generalized as provided in transit agency manuals. For example, some of the responses suggested the following:

- For transit stop planning, each context is different, and one should be very careful not to generalize. There are behavioral and cultural factors that are difficult to evaluate.
- Very few factors offer a consistent guide over an entire range of values - some of them even invert sign for some magnitudes and for some cities.
- There are so many factors affecting the transit stop planning – what we can put and where we can put it, but, it will be tough to find such a guideline which can work for all municipalities/agencies.

### 7.2 Research Limitations and Future Recommendations

The limitations of this research can be attributed mainly to the lack of data, resources, and time. These limitations are given as follows:

1. The stop allocation approach developed in Section 6.4.2 is based on some manual work besides using the developed Excel-tool. This limitation of Excel-tool can be overcome by automating the developed algorithm in ArcGIS to extract the spatial and demographical information about an area and as a result, give the optimum stops in the selected area. The attribute table of the final stops can be programmed to give the final rating of every factor. This result representation on a map will further help the transit planner to interpret the results. Further, in this stop allocation example, initialization was performed at 200m stop spacing, which resulted in uniform stop spacing throughout the street. In ArcGIS based program, this initialization can be programmed to be at small distance like every 10m. Small distances at initialization will result in more realistic stop allocation.

2. Ridership increases when more passengers use the transit system. Therefore, transit users’ opinion must be considered while planning a transit stop. However, in this study, transit expert’s opinion was considered to develop the tool.

3. Transit stop design is an expensive component in transit planning. This cost increases with increasing the amenities which are provided at the stop. The index-based tool developed in Chapter 6 can be helpful in deciding the amenities for improving passenger comfort but it did not analyze the cost efficiency or benefit to cost ratio from economical
point. However, this efficiency can be improved by adding the cost component to the model and analyzing the final index as a function of cost and order of priority.

4. To capture the full frame, both operational and stop-related factors must be studied in one tool. The tool developed in this study only rate a transit stop based on stop-related factors. This adds biasness in the result. In future, a tool can be developed which is sensitive to both these main criterions and gives a more realistic rating of a transit stop.

5. The responses received from the experts broadly suggest the followings:

- Operational factors also need to be included in transit stop planning process. These operational factors include, but are not limited to; headways, alternative travel congestion, service frequency, span of hours, start & end time of service, minimum and maximum trip times, vehicle loading, number of transfers, collision rate / bus in-service rate, specialized transit services, transferability to other transit agencies, service type, travel time, directness of service (minimize route diversions), availability of higher-order transit, service reliability (including things like transit priority measures to lessen traffic congestion impacts), overcrowding (or lack thereof), fare system (incentives, ease of payment, ridership costs, ridership subsidies), and quality of operation (cleanliness, driver behavior).

- Service integration and fare integration with other providers or higher order services also impact riders’ choice (auto driver, auto-passenger, transit).

- Political factors weigh heavily on amenities. Heavy commuter rail and surface feed routes vs spine surface high frequency routes add weight. Real time information is causing reduction of use of stop amenities such as need for shelters or a bench.

- Network externalities in terms of effective overall service are also important for ensuring that the starting point is in the right space in terms of overall coverage, level of security and comfort offered to passengers. Pricing, school board policies, and responses to the evolving impact of Vehicle-for-Hire on short term transit volumes, and long-term car ownership, also need to be considered.

- The correlation between stop spacing and service speed is very important. The more often the bus needs to stop, the slower the speed. In North America, stop spacing tends to be closer and service speed slower than in Europe. This affects the attractiveness of transit and is an area that deserves more in-depth research.
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Appendix: Expert Opinion Survey

Dear Survey Respondent,

You have been selected to participate in a research study led by researchers at the School of Engineering, University of British Columbia (Okanagan campus). The purpose of this study is to (a) understand the relative importance of various transit stop planning factors and (b) develop a bus stop rating index through the solicitation and synthesis of experts’ opinions. The proposed rating index is intended to help transit planners evaluate street transit (e.g. bus and streetcar) stops considering various factors related to stop location, interspacing, and design that affect transit ridership. Factors related to transit operations are not considered in this study.

The survey is divided into two sections: Section A will gather the relative importance of pairs of street transit stop planning factors (e.g. land use, comfort, safety, security, and cleanliness) with respect to attractiveness to passengers. Section B, on the other hand, will collect best-practices used in the transit industry to select typical values or ranges of those factors identified in Section A.

The survey sample includes experts concerned with the planning of urban transit systems across Canada. We kindly ask you to participate in this survey so that your opinions would be represented in our study. This survey is uniquely tied to your email address; please do not forward this survey to others.

This survey is designed to be as short as possible. It consists of 11 questions in Part A (with 40 pairwise comparisons) and 34 questions in Part B. The survey is expected to take approximately 30 minutes to complete. Please note that this survey can be completed in multiple sessions. If web cookies are enabled on your internet browser, you can leave an initial session and then complete the questionnaire at a later time. Your time and effort are very much appreciated. You can also save a copy of your responses at the completion of survey.

Please note that this is a voluntary participation and there are no associated risks greater than what you would experience in your daily life. You may also decline to enter or withdraw from the study at any time without any consequences. This online questionnaire is administered by the UBC Survey Tool. All data will be stored and backed up in Canada. Your responses will be held confidential, only high-level facts will be publically available on the internet via UBC citRcle after being anonymized. However, raw data will be stored by Dr. Ahmed Idris for any future studies. Documents (including electronic files and transcriptions) will be retained for a minimum of five years after publication and will be securely stored on UBC Okanagan Campus. Statistical data (without any personal identification) will be stored on Dr. Ahmed Idris’s office computer, which is password protected. If you have any concerns or complaints about your rights as a research participant and/or your experiences while participating in this study, please contact the Research Participant Complaint Line in the UBC Office of Research Services at 1-877-822-8598 or the UBC Okanagan Research Services Office at 250-807-8832. It is also possible to contact the Research Participant Complaint Line by email at RSIL@ors.ubc.ca. Any inquiries concerning the procedures should be directed to:

Primary Investigator:
Dr. Ahmed Idris, Assistant Professor, UBCO School of Engineering.
Phone: +1-250-807-9809 email: ahmed.idris@ubc.ca.

Co-Investigator:
Hassaan Masood, MASc Student, UBCO School of Engineering.
Phone: +1-250-859-3293 email: hasaan.masood@alumni.ubc.ca

By pressing the "Next" button below, you are consenting to participate in this research after carefully reading and fully understanding the information presented in the introductory section of the survey.
Expert Opinion Survey for Street Transit Stop Planning

Professional Information

City of employment:  
Type here

Years of experience:  
Type here
Section A. Transit Stop Factors Prioritization

In this section, you will be provided with pairs of street transit (e.g., bus and streetcar) stop planning factors/indicators. Using a 5-point bipolar scale, you will be asked to indicate the relative importance of the presented factors/indicators with respect to passengers’ attraction, as shown in the example below.

Important Definitions:

- Factors refer to transit stop characteristics or amenities that are controlled by the transit planner such as stop spacing and location, information provision, availability of shelter, seats, and heating system.
- Indicators refer to input field values that are uncontrolled by the transit planner and suggest the required factor level or need such as number of passengers required to offer a shelter or a seat.

Illustrative Example:

Using the provided bipolar scales, indicate the relative importance of the following pairs of street transit stop location factors to increase transit ridership (i.e., which factor is more influential on transit ridership?)

- If one factor is strongly more important than the other:
  - Access/egress distance to/from the stop
  - Longitudinal slope of sidewalk/bike path to/from the stop
  - OR
  - Access/egress distance to/from the stop
  - Longitudinal slope of sidewalk/bike path to/from the stop

- If one factor is more important than the other:
  - Access/egress distance to/from the stop
  - Longitudinal slope of sidewalk/bike path to/from the stop
  - OR
  - Access/egress distance to/from the stop
  - Longitudinal slope of sidewalk/bike path to/from the stop

- If the two factors are equally important:
  - Access/egress distance to/from the stop
  - Longitudinal slope of sidewalk/bike path to/from the stop
Expert Opinion Survey for Street Transit Stop Planning

Show Illustrative Example

- Yes
- No

Which of the following **stop location factors** is more important to increase transit ridership?

<table>
<thead>
<tr>
<th>Access by walk/cycle</th>
<th>Access by car (park and ride)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access/egress distance to/from the stop by walk/cycle</td>
<td>Longitudinal slope of sidewalk/bike path to/from the stop</td>
</tr>
<tr>
<td>Average household income within stop catchment area</td>
<td>Average population age within stop catchment area</td>
</tr>
<tr>
<td>Percent of seniors (≥ 60 years) within stop catchment area</td>
<td>Percent of juniors (&lt; 18 years) within stop catchment area</td>
</tr>
<tr>
<td>Accessibility to/from stop (walking/cycling distance and longitudinal slope)</td>
<td>Land use mix within catchment area (residential, commercial, Industrial, etc.)</td>
</tr>
<tr>
<td>Accessibility to/from stop (walking/cycling distance and longitudinal slope)</td>
<td>Demographics within catchment area (income and age)</td>
</tr>
<tr>
<td>Land use mix within catchment area (residential, commercial, Industrial, etc.)</td>
<td>Demographics within catchment area (income and age)</td>
</tr>
</tbody>
</table>

Which of the following **spatial and demographic factors** is more important to increase transit ridership?

| Location of individual transit stop (accessibility to/from stop, land use mix, and demographics within catchment area) | Spacing between two consecutive transit stops |
Which of the following indicators is most important to decide whether to provide a shelter?

- Precipitation level (snowfall and rainfall)
- Sunshine level

Which of the following indicators is more important to decide whether to provide a heating system?

- Prevailing temperature

Which of the following indicators is more important to decide whether to provide seats/benches?

- Average waiting time of transit user(s)
Expert Opinion Survey for Street Transit Stop Planning

Show Illustrative Example

- Yes
- No

Which of the following passenger comfort factors is more important to increase transit ridership?

- Availability of shelter
- Availability of seats / benches
- Availability of transit stop flag
- Availability of heating system
- Availability of Wi-Fi
- Availability of vending machines
- Availability of ticket machines
- Availability of enhanced amenities (heating system, Wi-Fi, vending and ticket machines)

Which of the following information provision factors is more important to increase transit ridership?

- Availability of static schedule information
- Availability of real time information
- Availability of Information map
Which of the following **equity and safety factors** is more important to increase transit ridership?

| Availability of tactile warning strips | Availability of sidewalk corridor |
| Availability of tactile warning strips | Availability of vertical gap |
| Availability of tactile warning strips | Availability of horizontal gap |
| Availability of sidewalk corridor | Availability of vertical gap |
| Availability of sidewalk corridor | Availability of horizontal gap |
| Availability of vertical gap | Availability of horizontal gap |

Which of the following **security factors** is more important to increase transit ridership?

| Availability of stop light | Availability of CCTV camera |

Which of the following **stop design factors** is more important to increase transit ridership?

| Availability of Information provision factors (static schedule information, real time information, and information map) | Availability of passenger comfort factors (seats, shelter, WiFi, and heating system) |
| Availability of information provision factors (static schedule information, real time information, and information map) | Availability of safety and equity factors (surface marking, vertical and horizontal gaps, sidewalk corridor) |
| Availability of Information provision factors (static schedule information, real time information, and information map) | Availability of security factors (stop light and CCTV) |
| Availability of passenger comfort factors (seats, shelter, WiFi, and heating system) | Availability of safety and equity factors (surface marking, vertical and horizontal gaps, sidewalk corridor) |
| Availability of passenger comfort factors (seats, shelter, WiFi, and heating system) | Availability of security factors (stop light and CCTV) |
| Availability of safety and equity factors (surface marking, vertical and horizontal gaps, sidewalk corridor) | Availability of security factors (stop light and CCTV) |

Which of the following factors is more important to increase transit ridership?

| Spatial and demographic factors (location of individual stop, spacing between two stops) | Design factors (passenger comfort, information provision, equity, safety, and security factors) |
For any other specific comments regarding Section A, please write here: (Optional)

Type here
Section B. Best-practices in Street Transit Stop Planning

Illustrative Example

In this section, you will be provided with a number of street transit (e.g. bus and streetcar) stop planning factors. For each factor, you will be asked to provide the typical values/ranges you would recommend to improve passengers’ perception of the service and increase transit ridership, as shown in the cases below.

**CASE 1: Factors with Three Categories (i.e. Excellent, Acceptable, and Unacceptable)**

Assume that the typical ranges for walk distance to/from a street transit stop are as follows:

<table>
<thead>
<tr>
<th>Category</th>
<th>Range (m)</th>
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</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>0 - 400</td>
</tr>
<tr>
<td>Acceptable</td>
<td>400 - 800</td>
</tr>
<tr>
<td>Unacceptable</td>
<td>&gt; 800</td>
</tr>
</tbody>
</table>

You can enter the previous information into the survey tool as follows:

**CASE 2: Binary Factors (i.e. Acceptable / Unacceptable)**

Assume that the typical ranges for walk distance to/from a street transit stop are as follows:

<table>
<thead>
<tr>
<th>Category</th>
<th>Range (m)</th>
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<tbody>
<tr>
<td>Acceptable</td>
<td>≤ 400</td>
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</table>

You can enter the previous information into the survey tool as follows:

*For unspecified lower- or upper-limit, please enter -999 or 999, respectively.*

**Note:**

For any other factor categories or comments, please fill the textbox provided after each question.
Question 1: Ticket Machines - Number of transit users

Best-practices in transit service planning emphasize the importance of ticket machines at transit stops, but they do not suggest any particular values/ranges for the number of passengers required to decide whether to provide ticket machines. However, the feedback from the pilot survey we conducted as part of this research suggested the following values/ranges:

- A ticket machine could be provided if a minimum of 400 passengers use the transit stop per day.

Please enter the typical values/ranges you would recommend for the above mentioned factor into the designated cells below.

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<tr>
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<th>Acceptable</th>
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- Enter as three-level ranges
- Enter as one-level range
- I Don't Know

For any other comments/additional indicators, please fill the textbox below:

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**Question 2: Vending Machines - Number of transit users**

Best-practices in transit service planning suggest the following values/ranges for the number of passengers required to decide whether to provide vending machine at street transit (e.g. bus and streetcar) stops:

- A vending machine could be provided if a minimum of 50 passengers use the transit stop per day (Reference: [http://design.transportation.org/Documents/Chapter5.pdf](http://design.transportation.org/Documents/Chapter5.pdf)).

Please enter the typical values/ranges you would recommend for the above mentioned factor into the designated cells below.

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For any other comments/additional indicators, please fill the textbox below:

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**Question 3: Wi-Fi - Number of transit users**

Best-practices in transit service planning emphasize the importance of Wi-Fi at transit stops, but they do not suggest any particular values/ranges for the number of passengers required to decide whether to provide Wi-Fi. However, the feedback from the pilot survey we conducted as part of this research suggested the following values/ranges:

- Wi-Fi could be provided if a minimum of 400 passengers use the transit stop per day.

Please enter the typical values/ranges you would recommend for the above mentioned factor into the designated cells below.
Question 4: Closed-Circuit Television (CCTV) Camera - Number of transit users

Best-practices in transit service planning emphasize the importance of CCTV Camera at transit stops, but they do not suggest any particular values/ranges for the number of passengers required to decide whether to provide CCTV Camera. However, research on human psychology discussed passengers' perception of security features as follows:


Please enter the typical values/ranges you would recommend for the above mentioned factor into the designated cells below.

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For any other comments/additional indicators, please fill the textbox below:

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Question 5: Stop Light - Number of transit users

Best-practices in transit service planning suggest the following values/ranges for the number of passengers required to decide whether to provide stop light at street transit (e.g. bus and streetcar) stops:

- Transit stop light is recommended if daily ridership is more than 10 (Reference: [http://www.trb.org/Publications/Blurbs/158910.aspx](http://www.trb.org/Publications/Blurbs/158910.aspx)).
- Lighting require at least 100 daily boardings (Reference: [https://www.nctr.usf.edu/pdf/77720.pdf](https://www.nctr.usf.edu/pdf/77720.pdf)).

Please enter the typical values/ranges you would recommend for the above mentioned factor into the designated cells below.

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For any other comments/additional indicators, please fill the textbox below:

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Question 6: Shelter - Average daily precipitation

Best-practices in transit service planning suggest the following values/ranges for the average daily precipitation required to decide whether to provide shelter at street transit (e.g. bus and streetcar) stops:

- Shelter is recommended if average daily precipitation is more than 2.5cm. Without a shelter, rain or snowfall would result in 5.95% or 13.10% decrease in ridership, respectively (Reference: http://scholarcommons.usf.edu/cgi/viewcontent.cgi?article=1098&context=jpt).

Please enter the typical values/ranges you would recommend for the above mentioned factor into the designated cells below.

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For any other comments/additional indicators, please fill the textbox below:

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Question 7: Shelter - Number of transit users

Best-practices in transit service planning suggest the following values/ranges for the number of transit users required to decide whether to provide shelter at street transit (e.g. bus and streetcar) stops:

- Shelter is recommended if daily ridership is 50 to 100 boardings per day in urban areas, more than 25 boardings per day in suburban areas, and more than 10 boardings per day in rural areas (Reference: http://nacto.org/docs/usdg/tcrp_report_19.pdf).

- Shelters should be provided at all transit stops serving 15 or more passengers per day (Reference: http://www.folsomaquaticcenter.com/city_hall/questysweb_agenda/MG64043/AS64051/AI65050/DO65703/1.PDF).

- Shelter provision will require at least 100 daily boardings (Reference: http://teachamerica.com/tih/PDF/transit-design-manual.pdf).

Please enter the typical values/ranges you would recommend for the above mentioned factor into the designated cells below.
Question 8: Shelter - Weeks of bright sunshine in a year

Best-practices in transit service planning emphasize the importance of shelter at transit stops, but they do not suggest any particular values/ranges for the number of weeks of bright sunshine required to decide whether to provide shelter. However, the feedback from the pilot survey we conducted as part of this research suggested the following values/ranges:

- A shelter could be provided if the number of bright sunshine weeks exceeds 4 in a year.

Please enter the typical values/ranges you would recommend for the above-mentioned factor into the designated cells below.

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For any other comments/additional indicators, please fill the textbox below:

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Question 9: Heating System - Weeks of freezing temperature in a year

Best-practices in transit service planning emphasize the importance of heating system at transit stops, but they do not suggest any particular values/ranges for the number of weeks of freezing temperature required to decide whether to provide heating system. However, the feedback from the pilot survey we conducted as part of this research suggested the following values/ranges:

- Heating system could be provided if number of weeks (in a year) in which temperature in less than -3°C exceeds 4.

Please enter the typical values/ranges you would recommend for the above-mentioned factor into the designated cells below.

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For any other comments/additional indicators, please fill the textbox below:

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Question 10: Heating System - Number of transit users

Best-practices in transit service planning emphasize the importance of heating system at transit stops, but they do not suggest any particular values/ranges for the number of transit users required to decide whether to provide heating system. However, the feedback from the pilot survey we conducted as part of this research suggested the following values/ranges:

- Heating system could be provided if daily ridership is more than 15.

Please enter the typical values/ranges you would recommend for the above-mentioned factor into the designated cells below.
Best-practices in transit service planning suggest the following values/ranges for the access/egress distance to/from street transit (e.g. bus and streetcar) stops to maintain accessibility by walk and cycle:

- An area is considered “well-served” if a stop is no more than 400 m from passenger’s origin point, whereas an area is considered “served” if a stop is no more than 800 m from passenger’s origin point (Reference: [http://www.nctr.usf.edu/pdf/77720.pdf](http://www.nctr.usf.edu/pdf/77720.pdf)).
- A 300 m or less, equivalent to 5 min or less, is considered a reasonable walking distance to/from transit stops (Reference: [https://bctransit.com/servlet/documents/1403640670226](https://bctransit.com/servlet/documents/1403640670226)).

Please enter the typical values/ranges you would recommend for the above-mentioned factor into the designated cells below.
Question 12: Access by Walk and Cycle - Longitudinal slope of sidewalk to/from the stop

Best-practices in transit service planning suggest the following values/ranges for the longitudinal slope of sidewalk corridor to/from street transit (e.g. bus and streetcar) stops to maintain accessibility by walk and cycle:

- If unavoidable, stops on steep hills should be placed at the section of the slope with a gradient less than 8% for proper wheelchair maneuverability (Reference: https://bctransit.com/servlet/documents/1403640670226).

- The longitudinal slope of the sidewalk (often determined by the slope of the street) should not exceed 5.0% for suitable pedestrian mobility and proper wheelchair maneuverability (Reference: https://www.fhwa.dot.gov/environment/bicycle_pedestrian/publications/sidewalk2/sidewalks204.cfm).

Please enter the typical values/ranges you would recommend for the above-mentioned factor into the designated cells below.
Question 13: Transit Stop Flag

Best practices in transit service planning suggest the following values/ranges for the height of street transit (e.g. bus and streetcar) stop flag:

- It is recommended to be in a range of 2m to 3m (Reference: http://nacto.org/docs/usdg/bus_stop_safety_design_guidelines_kimley.pdf).
- The bottom of the sign should not be less than 2.5m above ground level (Reference: https://www.planningni.gov.uk/downloads/bus-stop-designguide.pdf).

Please enter the typical values/ranges you would recommend for the above-mentioned factor into the designated cells below.

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For any other comments/additional indicators, please fill the textbox below:

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Question 14: Seats / Benches - Number of transit users

Best practices in transit service planning suggest the following values/ranges for the number of transit users required to decide whether to provide seats/benches at street transit (e.g. bus and streetcar) stops:

- Seating should be provided at all transit stops serving 5 or more passengers per day (Reference: http://www.folsomaquaticcenter.com/city_hall/questysweb/agenda/MG64043/AS64051/Al65050/DO65703/1.PDF).

Please enter the typical values/ranges you would recommend for the above-mentioned factor into the designated cells below.
Question 15: Seats / Benches - Waiting time of transit user(s)

Best-practices in transit service planning suggest the following values/ranges for the waiting time of transit user(s) required to decide whether to provide seats/benches at street transit (e.g. bus and streetcar) stops:

- Seats are provided if waiting time of user exceeds 15 min (Reference: https://www.nctr.usf.edu/pdf/77720.pdf).
- If waiting time is 30 to 60 min, seats can be useful. If waiting time is 2 to 6 min, seats may not be useful (Reference: Pilot Survey).

Please enter the typical values/ranges you would recommend for the above-mentioned factor into the designated cells below.
Best-practices in transit service planning suggest the following values/ranges for the vertical gap at street transit (e.g. bus and streetcar) stops:

- To provide accessible boarding, the vertical step between a platform and a vehicle (or ramp) must not exceed 16mm (Reference: [http://nacto.org/publication/transit-street-design-guide/](http://nacto.org/publication/transit-street-design-guide)).

- 0 to 50mm is Accessibility target, 50mm to 100mm is usable with difficulty and above that is not accessible (Reference: [http://www.icevirtuallibrary.com/isbn/9780727737083](http://www.icevirtuallibrary.com/isbn/9780727737083))

Please enter the typical values/ranges you would recommend for the above-mentioned factor into the designated cells below.
Question 17: Horizontal Gap

Best-practices in transit service planning suggest the following values/ranges for the horizontal gap at street transit (e.g. bus and streetcar) stops:

- To provide accessible boarding, the horizontal gap between a platform and a vehicle (or ramp) must not exceed 76mm (Reference: https://nacto.org/publication/transit-street-design-guide/).

- 0 to 50mm is accessibility target, 50mm to 100mm is usable with difficulty and above that is not accessible (Reference: http://www.icevirtuallibrary.com/isbn/97807277737083).

Please enter the typical values/ranges you would recommend for the above-mentioned factor into the designated cells below.

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For any other comments/additional indicators, please fill the textbox below:

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Question 18: Sidewalk Corridor

Best-practices in transit service planning suggest the following values/ranges for the width of walkway at street transit (e.g. bus and streetcar) stop:

- It is recommended to be in a range of 1.2m to 1.5m (Reference: http://nacto.org/docs/usdg/us_stop_safety_design_guidelines_kimley.pdf).

Please enter the typical values/ranges you would recommend for the above-mentioned factor into the designated cells below.
Best practices in transit service planning suggest the following values/ranges for the width of tactile warning strips at street transit (e.g. bus and streetcar) stop:

- Tactile warning strips must be at least 0.5m deep (Reference: [https://nacto.org/publication/transit-street-design-guide/](https://nacto.org/publication/transit-street-design-guide)).
- It is recommended to be at least 0.6m (Reference: [https://www.planningni.gov.uk/downloads/busstop-designguide.pdf](https://www.planningni.gov.uk/downloads/busstop-designguide.pdf)).

Please enter the typical values/ranges you would recommend for the above-mentioned factor into the designated cells below.

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For any other comments/additional indicators, please fill the textbox below:

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Question 20: Information Map - Number of transit users

Best-practices in transit service planning suggest the following values/ranges for the number of passengers required to decide whether to provide information map at street transit (e.g. bus and streetcar) stops:

- Route info require at least 100 daily boardings (Reference: [http://www.nctr.usf.edu/pdf/77720.pdf](http://www.nctr.usf.edu/pdf/77720.pdf)).

Please enter the typical values/ranges you would recommend for the above-mentioned factor into the designated cells below.

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Enter as three-level ranges

Question 21: Static Schedule Information - Number of transit users

Best-practices in transit service planning suggest the following values/ranges for the number of passengers required to decide whether to provide static schedule information at street transit (e.g. bus and streetcar) stops:

- Route info require at least 100 daily boardings (Reference: [http://www.nctr.usf.edu/pdf/77720.pdf](http://www.nctr.usf.edu/pdf/77720.pdf)).

Please enter the typical values/ranges you would recommend for the above-mentioned factor into the designated cells below.

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Question 22: Real Time Information - Number of transit users

Best-practices in transit service planning suggest the following values/ranges for the number of passengers required to decide whether to provide real time information at street transit (e.g. bus and streetcar) stops:

- Route info require at least 100 daily boardings (Reference: http://www.nctr.usf.edu/pdf/77720.pdf).

Please enter the typical values/ranges you would recommend for the above-mentioned factor into the designated cells below.

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For any other comments/additional indicators, please fill the textbox below.

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Question 23: Percent of juniors (≤ 18 years) within stop catchment area

Best-practices in transit service planning suggest the following values/ranges for the percentage of juniors in street transit (e.g. bus and streetcar) stop catchment area:

- A transit stop is recommended for areas having children/youth population (under 18 years of age) exceeding 25% of total population (Reference: https://www.capmetro.org/uploadedFiles/Capmetroorg/About_Us/Service_Changes/capital-metro_service-guidelines-and-standards.pdf).

Please enter the typical values/ranges you would recommend for the above-mentioned factor into the designated cells below.
Question 24: Percent of seniors (≥ 60 years) within stop catchment area

Best-practices in transit service planning suggest the following values/ranges for the percentage of seniors in street transit (e.g. bus and streetcar) stop catchment area:

- A transit stop is recommended for areas having more number of elderly people (those persons over the age of 60) (Reference: http://teachamerica.com/tih/PDF/transit-design-manual.pdf).

- A transit stop is recommended for areas having elderly population (65 years of age and older) exceeding 10% of total population (Reference: https://www.capmetro.org/uploadedFiles/Capmetroorg/About_Us/Service_Changes/capital-metro_service-guidelines-and-standards.pdf).

Please enter the typical values/ranges you would recommend for the above-mentioned factor into the designated cells below.
Question 25: Average Household Income within Stop Catchment Area

Best-practices in transit service planning suggest the following values/ranges for the annual income in street transit (e.g. bus and streetcar) stop catchment area:

- A transit stop is recommended for areas having households with annual incomes less than $10,000 (Reference: https://www.nctr.usf.edu/pdf/77720.pdf).
- A transit stop is recommended for areas having average household income below 50% of regional median income (Reference: https://www.capmetro.org/uploadedFiles/Capmetroorg/About_Us/Service_Changes/capital-metro_service-guidelines-and-standards.pdf).

Please enter the typical values/ranges you would recommend for the above-mentioned factor into the designated cells below.

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For any other comments/additional indicators, please fill the textbox below:

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Question 26: Land Use within Stop Catchment Area – (I) Residential

Best-practices in transit service planning suggest the following values/ranges for the number of household units in street transit (e.g. bus and streetcar) stop catchment area:

- Residential areas with a minimum of 200 households are candidates for transit service (Reference: https://www.nctr.usf.edu/pdf/77720.pdf).
- Provide stops at residential areas with 500+ units (Reference: http://nacto.org/docs/usdg/bus_stop_safety_design_guidelines_kimley.pdf).

Please enter the typical values/ranges you would recommend for the above-mentioned factor into the designated cells below.
Question 27: Land Use within Stop Catchment Area – (II) Employment

Best-practices in transit service planning suggest the following values/ranges for the number of employees in street transit (e.g. bus and streetcar) stop catchment area:

- Transit service is considered to all work sites where 500 or more persons work for a single employer and where 1,000 or more persons work for several employers (Reference: https://www.nctr.usf.edu/pdf/77720.pdf).

- There is at least one large employer (2500+ employees) or three major employers (1000+ employees) (Reference: http://nacto.org/docs/usdg/bus_stop_safety_design_guidelines_kimley.pdf).

Please enter the typical values/ranges you would recommend for the above-mentioned factor into the designated cells below.
Question 28: Land Use within Stop Catchment Area – (III) Commercial

Best-practices in transit service planning suggest the following values/ranges for the commercial land area in street transit (e.g. bus and streetcar) stop catchment area:

- Provide stops at retail centres with 400,000+ square feet of leasable space (Reference: http://nacto.org/docs/usdg/bus_stop_safety_design_guidelines_kimley.pdf).

Please enter the typical values/ranges you would recommend for the above-mentioned factor into the designated cells below.

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- Enter as three-level ranges
- Enter as one-level range
- I Don’t Know

For any other comments/additional indicators, please fill the textbox below:

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Question 29: Land Use within Stop Catchment Area – (IV) School Enrolment

Best-practices in transit service planning suggest following values/ranges for the school enrolments within street transit (e.g. bus and streetcar) stop catchment area:

- Provide stops at education centres with 2,500+ students (Reference: http://nacto.org/docs/usdg/bus_stop_safety_design_guidelines_kimley.pdf).

Please enter the typical values/ranges you would recommend for the above-mentioned factor into the designated cells below.

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Question 30: Stop Spacing - Central Business District (CBD)

Best-practices in transit service planning suggest following values/ranges for the street transit (e.g. bus and streetcar) stop spacing in Central Business District:

- Stop spacing can range from 200m to 300m, but typically can be 200m (Reference: https://bctransit.com/servlet/documents/1403640670226).

- For the central core/CBD, the stop spacing should be 90 to 300m; a typical spacing is 180m (Reference: https://www.nctr.usf.edu/pdf/77720.pdf).

- Stop spacing can typically be 400m (Reference: https://at.govt.nz/media/imported/4394/AT-ARTA-Guidelines-Bus%20Stop%20Infrastructure%20Guidelines%202009.pdf).

Please enter the typical values/ranges you would recommend for the above-mentioned factor into the designated cells below.

For any other comments/additional indicators, please fill the textbox below:

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Question 31: Stop Spacing - Urban Areas

Best-practices in transit service planning suggest following values/ranges for the street transit (e.g. bus and streetcar) stop spacing in urban areas:

- Stop spacing can range from 200m to 365m, but typically can be 200m (Reference: https://bctransit.com/servlet/documents/1403640670226).
- For urban areas, the stop spacing should be 152 to 365m; a typical spacing is 180m (Reference: https://www.nctr.usf.edu/pdf/77720.pdf).
- Stop spacing can range from 200m to 400m (Reference: https://at.govt.nz/media/imported/4394/AT-ARTA-Guidelines-Bus%20Stop%20Infrastructure%20Guidelines%202009.pdf).

Please enter the typical values/ranges you would recommend for the above-mentioned factor into the designated cells below.

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- Excellent: [auto filled]

Enter as three-level ranges

- Enter as one-level range
- I Don't Know

For any other comments/additional indicators, please fill the textbox below

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Question 32: Stop Spacing - Suburban Areas

Best-practices in transit service planning suggest following values/ranges for the street transit (e.g. bus and streetcar) stop spacing in sub-urban areas:

- Stop spacing can range from 200m to 760m, but typically can be 300m (Reference: https://bctransit.com/servlet/documents/1403640670226).
- Stop spacing can range from 183m to 762m, but typically can be 305m (Reference: https://www.nctr.usf.edu/pdf/77720.pdf).
- Stop spacing can range from 150m to 305m (Reference: http://septa.org/strategic-plan/reports/service-standards-2014.pdf).

Please enter the typical values/ranges you would recommend for the above-mentioned factor into the designated cells below.
Stop spacing can range from 200m to 800m, but typically can be 380m (Reference: https://bctransit.com/servlet/documents/1403640670226).

Stop spacing can range from 198m to 805m, but typically can be 381m (Reference: https://www.nctr.usf.edu/pdf/77720.pdf).


Stop spacing can range from 800m to 1000m (Reference: https://at.govt.nz/media/imported/4394/AT-ARTA-Guidelines-Bus%20Stop%20Infrastructure%20Guidelines%202009.pdf).

Please enter the typical values/ranges you would recommend for the above-mentioned factor into the designated cells below.
Question 34: Park and Ride facility - Number of Driving Transit Users

Best-practices in transit service planning suggest following values/ranges for the number of driving transit users required for providing park-and-ride facility at street transit stop:

- Park-and-ride facilities may be provided at any suitable location which can be shown to attract 200 autos per day for express service and 150 autos per day for limited stop service (Reference: https://www.nctr.usf.edu/pdf/77720.pdf).

Please enter the typical values/ranges you would recommend for the above-mentioned factor into the designated cells below.

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For any other comments/additional indicators, please fill the textbox below:

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Feedback on Survey:

Does the survey cover all factors that affect transit ridership?

Strongly Agree [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ] Strongly Disagree

Please mention any other factor(s) that can be considered (optional):

Type here