INDEX-BASED DECISION-SUPPORT TOOL
FOR TRANSIT STOP PLANNING UNDER UNCERTAINTIES

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1.0 Introduction

Transit stops serve as pivot points between the passengers and the transit service that control passengers' perception and eventually transit ridership. Numerous spatial, socio-economic, and demographic factors are important for proper selection of stop locations (Foda & Osman, 2010). Land use density and mix at the stop catchment area have a pronounced effect on transit ridership. Among all land use densities, residential and employment densities have shown the strongest effect on transit ridership. Optimum stop spacing can improve transit running time by 6% (EI-Geneidy, Strathman, Kimpel, & Crout, 2006). Among various socio-economic factors, the income level within the stop catchment area is of utmost importance for estimating transit ridership (Liu, 1993). Besides the spatial, socio-economic, and demographic factors, the design of the transit stop improves riders' satisfaction and waiting experience at the stop, which leads to improved ridership. According to a study in Vancouver, British Columbia, improvements in transit stop design could increase ridership by 45% (Zhang, 2012).

Different mathematical approaches have been developed to deal with transit stop planning problems. While useful, traditional transit stop planning approaches neglect the interdependencies and uncertainty associated with the factors involved. The presence of uncertainty means that if an 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). In this study, the uncertainties associated with transit planning are classified as parametric, model, and scenario uncertainty.

First, parameter uncertainty originates from estimation of factor values in the model. The values of factors obtained from design manuals of different transit agencies are different from each other. For example, BC Transit (BC Transit, 2010) recommends a maximum of 8% gradient for transit stop location but another research limits it to 4% (Furth & SanClemente, 2006). These differences in benchmarks add parametric uncertainty in the transit stop planning process. Second, model uncertainty arises in the model structure being used for transit stop evaluation, when simplified assumptions are made to reach the endpoint. Some model uncertainties also occur due to wrong relationships between factors, this is referred to as relationship error. For example, TCRP 19 recommends that factors like number of transit users, transit stop width, waiting time, weather condition, sidewalk width, and distance of fire hydrant tank may be considered in providing seats at a transit stop. 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. Therefore, only number of transit users is used in this study to decide seat provision. This simplification of factors cause model uncertainty. Third, 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 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. Mostly, transit trip planning is based on an average value of factors involved and do not dynamically respond to the change in conditions.

Multi-agent approaches have been proposed to solve the diverse transportation engineering problems. Major drawbacks of using multi-agent approaches are unpredictable outcome of interaction and difficulty in predicting the outcome of overall system. To overcome the limitations of agent-based approaches, the Fuzzy Set Theory (FST), proposed by Zadeh (Zadeh, 1965), is used to solve nonlinear problems which involve ambiguity and vagueness. Many problems in the field of transportation are ill defined, uncertain and overlapping with each other. Subjective judgment is present in making decisions regarding transit stops. Therefore, in this study, the FST is used that recognize the vague boundary between parameters.

2.0 Methodology

2.1 Fuzzy Synthetic Evaluation

The Fuzzy Set Theory (FST) is widely used to incorporate experts' opinions in decision-making (Zadeh, 1965). In this study, the Fuzzy Synthetic Evaluation (FSE) is used to generate the rating index. The FSE uses fuzzy mathematics to transmute imprecise information using the following steps:

2.1.1 Framework Generation and Fuzzification

The aggregate output of the FSE is based on a hierarchical framework where system factors are categorized and arranged such that the output function is located at the top level followed by the basic factors at the most bottom level. At the most bottom level, factors are defined such that further disaggregation is not possible (Sadiq, Husain, Veitch, & Bose, 2004).

Three categories of level of service were defined in this study; *Excellent*, *Acceptable*, and *Unacceptable* and each category was bounded by benchmarks. Categories and benchmarks, together are called a membership function. Membership functions can be of any shape, however, in this study, a triangular membership function is used to form fuzzy sets. Fuzzification refers to the process of how information is perceived, membership functions are generated, and fuzzy sets are formed. The fuzzy set is formed by mapping each input variable to the predefined membership functions, as shown in Table 1.

2.1.2 Prioritization and Aggregation

In the FSE, factors are assigned weights based on their relative importance based on Analytic Hierarchy Process (AHP), designed by Thomas L. Saaty in 1971 (Saaty, 1980). After weights are assigned, aggregation is performed to synthesize the lower level (local) weights into upper level (global) weights by performing matrix operations on weight vector and evaluation matrix of a particular level (Khatri, Vairavamoorthy, & Akinyemi, 2011).

2.1.3 Defuzzification

It is often difficult to make decisions on some ambiguous information. A crisp mathematical integer makes it easy to decide on the best optimum result. In this study, the scoring method of defuzzification, as adopted by (Sadiq et al., 2004) is applied. The scoring method can be presented mathematically as follows:

$$Defuzzification = \sum_{i=1}^{n} \delta_i \mu_i$$

where:

δ: Relative weight coefficient
μ: Membership function
n: Granularity

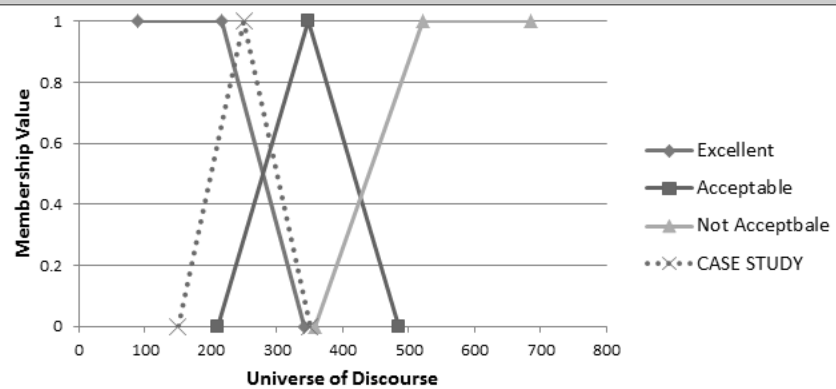
2.2 Transit Stop Evaluation Framework

The proposed tool is intended to help decision-makers evaluate existing/new transit stop(s). Based on Fuzzy Set Theory, the developed tool generates a transit stop rating index considering transit stop spacing, location, and design factors. The developed tool allows transit planners to select factors and establish the degree of fuzziness and benchmarks based on the site conditions.

This procedure makes Step 1 of framework. Because the priority of every city and agency is different for transit stop planning, the tool is also flexible to change the relative weights, which is Step 2 of framework. Then the information of stop being accessed in entered in the benchmarks menu and results are generated and conclusions are made, which is Step 3 of framework. The developed tool is threefold, as shown is Figure 1.

Table 1: Fuzzy Set Formation of Stop Spacing in Central Business District

Benchmarks and Membership Function	Excellent	Acceptable	Un-acceptable	Case Study
Lower Limit	90	300	400	150
Upper Limit	300	400	600	350
CV		42.4		
Fuzzification of Benchmarks				
Fuzzified LL	90	210.96	357.6	
Fuzzified UL	342.2	484.8	684.8	
Fuzzy Graphs				



Fuzzy Set				
Original	0.85	0.58	0.42	Σ=1.85
Normalized	0.46	0.31	0.23	Σ=1.0

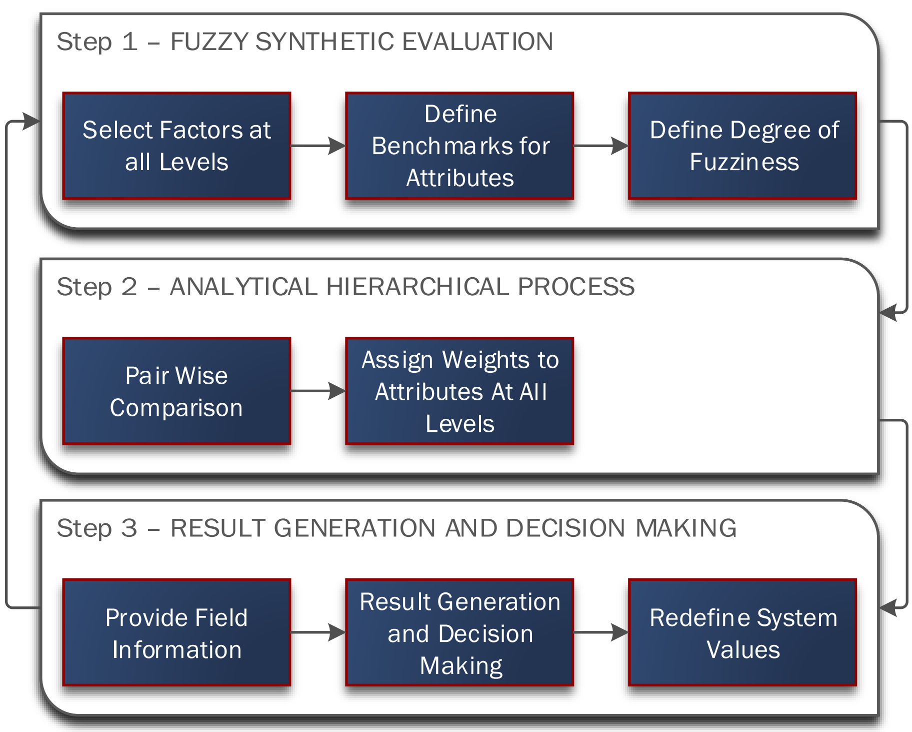


Figure 1: Framework for Transit Stop Planning Index

3.0 Application of Transit Evaluation Index

3.1 Location of Transit Stop

For the evaluation of existing transit stop, a transit stop was picked in the City of Kelowna, BC, as shown in Figure 2. It is a small stop with very basic infrastructure. Stop catchment area is a single use residential units. Bike-and ride or park-and ride facilities are not provided. Further, no information provision is provided at stop. From basic amenities, seats, garbage receptacle, and stop sign are provided but shelter is not provided. Which consequently infer that heating system or air-conditioning system is also not provided at this transit stop. In addition, none of enhanced amenities are provided which include Wi-Fi, vending machine or ticket machine. Taking equity into consideration, surface marking is also absent from this transit stop, however, side walk and vertical gap and horizontal gap are considered for appropriate access/egress of wheelchairs. To provide security to transit users, only stop light is provided. The indicator value for this stop is given in Table 2 below.

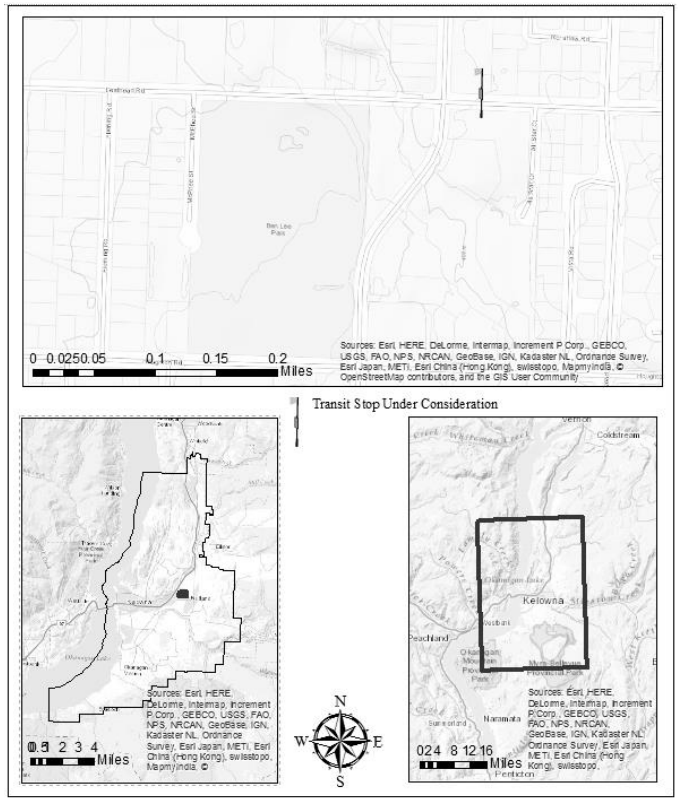


Figure 1: Transit Stop Under Consideration in the City of Kelowna, BC

3.2 Step 1(a): Selecting Appropriate Factors and Defining Degree of Fuzziness

Transit planners can identify only the relevant factors along with their degree of fuzziness (i.e. uncertainty). To make the tool more handy, two filters are applied, as shown in figure 3. First filter "Required or Not" manage whether a given factor is required in analysis or not. For most of design factors, the second filter is also applied in which determine that a specific factor is present at transit stop or not. For example, the transit planner may want to include "seats" in analysis but they are not present at transit stop. So, first filter will be "Required" and second filter will be "Not Provided".

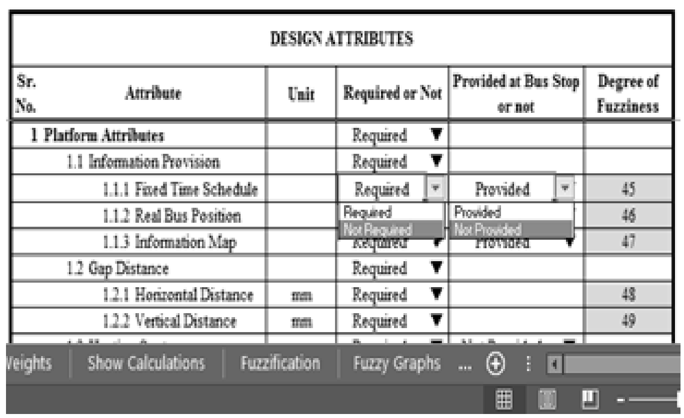


Figure 3: Factor Selection and Adjusting Filters

3.3 Step 1 (b): Defining Benchmarks

Although default values of benchmarks are given based on published literature and agency manuals, but user can change these default values to meet the specific site conditions. The excel interface of this step is given in Figure 4.

BENCHMARKS

Variables		Excellent		Acceptable		Unacceptable		Case Study	
Attributes	Units	Min	Max	Min	Max	Min	Max	Min	Max
Fixed Time Schedule									
1.1.1.1 Transit Users	No.	120	140	100	120	80	100	80	80
Real Bus Position									
1.1.2.1 Transit Users	No.	120	140	100	120	80	100	90	130
Information Map									
1.1.3.1 Transit Users	No.	120	140	100	120	80	100	90	130

Figure 4: Defining Benchmarks

3.4 Step 2: Defining Priorities

The prioritization of selected factors in done through Analytical Hierarchical Process. By default, priority of all factors is considered to be equal. This default prioritization is editable to match the specific site conditions. The excel interface of prioritization is given in Figure 5.

Accessibility		Position	Activity		Density
Accessibility	are	Very Strongly	More	important than	Position
Accessibility	are	Equal / Moderately / Strongly / Very Strongly	Equal / More / Less	important than	Activity
Accessibility	are			important than	Density
Position	are		Equal	important than	Activity
Position	are	Equal	Equal	important than	Density
Activity	are	Equal	Equal	important than	Density
Accessibility		Position	Activity		Density

Figure 5: Defining Priority

3.5 Step 3: Generating Results

The result is shown in form of a rating meter which has a maximum limit of 10 and minimum limit of 0. The result is obtained by analyzing the inputs provided by transit planners using Fuzzy Synthetic Evaluation. The excel interface of result is shown in Figure 6.

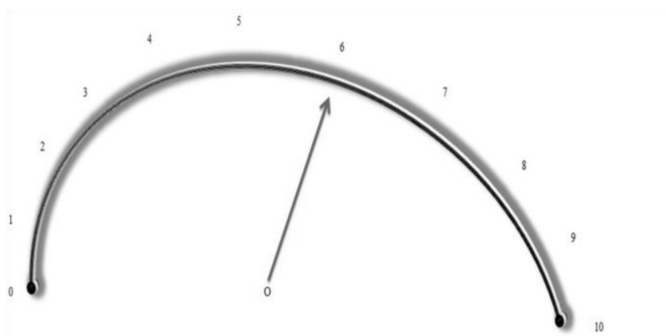


Figure 6: Final Output of Excel-Based Tool

4.0 Results and Discussion

In this study, the subjective nature of transit stop planning is transformed into quantitative measure using Fuzzy Synthetic Evaluation (FSE). For the required transit stop, the ultimate output is a meter showing result of 6 out of 10. It means that transit stop is not at its best condition but also not worse, and it performing in middle. But it can be improved. For example, as seen from Appendix A, the benchmarks for providing fixed time schedule shows that if transit user is low (80 to 100), there is no need to provide fixed time schedule. But in solved example, fixed time schedule is provided. If meeting the demand, fixed time schedule is removed from the transit stop, the ranking can be improved.

5.0 Conclusions

This paper introduced a transit stop planning tool for evaluating the spacing, location, and design of existing/new transit stop(s) using a transit stop rating index. The rating index accounts for various transit stop planning factors along with their interdependencies and the uncertainty associated with their ranges. As opposed to pure mathematical fundamentals and concepts, the principles of Fuzzy Set Theory (FST) were used. To account for the variability in service planning standards and guidelines among different transit agencies, the developed tool provides transit planners with the flexibility to select relevant factors and change their ranges from a set of recommended default values. For illustration, a random transit stop was evaluated using the developed tool to demonstrate the applicability of tool in practical situations. However, the factor values used for this illustrative example is only assumption based and does not show the real data. Further, the socio-economic and demographic data and ridership data is confidential and is not used in this paper.

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Table 2: Default Benchmarks of Factors Used in This Study

Sr. No.		Category	Factor		Coefficient of Variation	Excellent		Acceptable		Unacceptable	
			Description	**Unit**	**CV**	**LL**	**UL**	**LL**	**UL**	**LL**	**UL**
1	1.1	Spatial and Demographic Factors	Walking distance (access/egress) recommended for pedestrian users	m	25	0	400	400	800	800	1000
	1.2		Number of Driving Transit Users (DTUs) recommended for providing Park-and-Ride facility	No.	26	150	200	100	150	0	100
	1.3		Longitudinal grade of sidewalk corridor recommended for safety of pedestrians and wheelchair users	%age	27	0	5	5	8	8	12
	1.4		Number of residential units recommended for providing a transit stop	No.	28	500	800	200	500	0	200
	1.5		Number of working people recommended for providing a transit stop	No.	29	2500	5000	1000	2500	0	1000
	1.6		Commercial land area recommended for providing a transit stop	sq.km.	30	400	1000	300	400	0	300
	1.7		Number of school enrolments recommended for providing a transit stop	No.	31	2500	5000	2000	2500	0	2000
	1.8		Average household income recommended for providing a transit stop	CAD$	32	0	8,000	8,000	12,000	12,000	20,000
	1.9		Percentage of elderly people recommended for providing a transit stop (years)	No.	33	65	90	50	65	0	50
	1.10		Percentage of minors recommended for providing a transit stop (years)	No.	34	0	16	16	20	20	25
	1.11		Stop spacing recommended in Central Business District (CBD) area of city	m	35	90	300	300	400	400	800
	1.12		Stop spacing recommended in urban area of city	m	36	200	365	365	500	500	900
	1.13		Stop spacing recommended in suburban area of city	m	37	200	765	765	1000	1000	1500
	1.14		Stop spacing recommended in rural area of city	m	38	200	800	800	1200	1200	2000
2	2.1	Design Factors	Number of transit users recommended for providing static schedule information at transit stop	No.	25	100	200	80	100	0	80
	2.2		Number of transit users recommended for providing real time information at transit stop	No.	26	100	200	80	100	0	80
	2.3		Number of transit users recommended for providing information map at transit stop	No.	27	100	200	80	100	0	80
	2.4		Total annual precipitation recommended to providing shelter at transit stop	mm	28	900	1800	720	900	0	720
	2.5		Number of transit users recommended for providing shelter at transit stop	No.	29	40	100	15	40	0	15
	2.6		Prevailing temperature recommended for providing heating system in shelter at transit stop	°C	30	-27	-10	-10	-3	-3	0
	2.7		Number of transit users recommended for providing heating system in shelter at transit stop	No.	31	15	50	10	15	0	10
	2.8		Number of transit users recommended for providing garbage receptacles at transit stop	No.	32	60	100	40	60	0	40
	2.9		Number of transit users recommended for providing seats at transit stop	No.	33	50	100	5	50	0	5
	2.10		Recommended height of transit stop sign	m	34	2.5	3	2	2.5	0	2
	2.11		Recommended width of tactile warning strips for safety	m	35	0.6	0.8	0.5	0.6	0.0	0.5
	2.12		Recommended width of sidewalk corridor for safety	m	36	1.2	1.5	1.0	1.2	0	1.0
	2.13		Recommended vertical gap between transit stop platform and transit platform	mm	37	0	50	50	100	100	150
	2.14		Recommended horizontal gap between transit stop platform and transit platform	mm	38	0	50	50	100	100	150
	2.15		Number of transit users recommended for providing stop light at transit stop for security	No.	39	8	20	5	8	0	5
	2.16		Number of transit users recommended for providing CCTV camera at transit stop for security	No.	40	10	50	5	10	0	5
	2.17		Number of transit users recommended for providing emergency service phone at transit stop for security	No.	41	50	100	40	50	0	40

LL = Lower Limit
UL = Upper Limit