

Transit Service Evaluation: A Time/Frequency-based Stop Accessibility Approach¹

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1 Introduction

Public transit is the workhorse of any urban transportation system, principally in sustainable, equitable, and livable cities. In addition to the three main stages of public transit planning: strategic planning, tactical planning, and operational planning (Ceder & Wilson, 1986); transit service evaluation is essential for insuring efficient and satisfactory transit systems. Transit service evaluation is a multifaceted process that is used for problem identification, reporting purposes, communicating results, target setting, and policy improvements (Barker et al., 2003; Dhingra, 2011). Therefore, transit service evaluation is a key procedure to ensure cost-efficient and effective public transit service (Mistretta, Goodwill, Gregg, & De Annuntis, 2009). Moreover, due to the uncertainties (e.g. demand variability, behavioural shifts, etc.) associated with human travel behaviour, transit service is constantly in need of fine-tuning at the strategic, tactical, and operational levels.

The primary goal of transit service evaluation is to increase transit ridership, and therefore, focusing on transit users' perspectives is essential in defining the evaluation criteria. Transit service accessibility and availability are among the foremost concerns of transit users (Mahmoud & Hine, 2013; Mahmoud & Hine, 2016; Ding & Zhang, 2016; Litman, 2017) and have a significant impact on transit ridership.

This paper adopts an inclusive definition of transit accessibility which combines the spatial (i.e. physical accessibility) and temporal (i.e. service availability) aspects of transit service. This composite is assembled in a Time/Frequency-based Stop Accessibility index, which reflects the suitability of the surrounding active transportation infrastructures of a stop as well as transit service availability at this stop for a predefined time period. Furthermore, this paper proposes a Stop Importance Index, which reflects the importance of the surrounding land uses with respect to their trip generation characteristics and considering their actual proximity to the stop. In addition to employing these indices independently, this paper provides helpful insights, through the integration of both indices, on stop utilization and the required levels of improvement.

The paper stands to offer practical contributions to transit planning, prioritizing quality improvements interventions, and guiding the decision-making process of transit provision.

The remainder of this paper is arranged as follows: Section 2 reviews the literature on transit service evaluation and different accessibility measures. Section 3 details the proposed methodology. Section 4 presents the results of applying the proposed methodology on the City of Kelowna transit system as a case study. Lastly, concluding remarks are presented in section 5.

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2 Literature review

Transit service evaluation is vital for transit operators as well as transit users. The evaluation process includes problem identification, policy modification, trend analysis, and peer comparisons (Dhingra, 2011). Transit service accessibility and availability are among the most common evaluation criteria for transit services (European Committee for Standardization, 2002; Barker et al., 2003; Mistretta et al., 2009; Litman, 2016; MBTA, 2017). Service accessibility is defined by transit practitioners (European Committee for Standardization, 2002; MBTA, 2017) as the availability of sidewalks, bike lanes, park and ride facilities, tickets, and transfers between transit modes. While service availability is defined as the span and frequency of the transit service along with service coverage (Barker et al., 2003; MBTA, 2017). Moreover, (European Committee for Standardization, 2002) also considers the number of transfers and the crowding level of transit units.

Mistretta et al. (2009) included route layout, stop spacing, and stop location in transit service availability. On the other hand, others like (Los Angeles County - Metropolitan Transportation Authority, 2015) define service accessibility as the availability of transit service within a quarter mile in metropolitan service areas. Therefore, especially from a practical standpoint, transit service accessibility and availability are mutually inclusive and could be used interchangeably as the service is not accessible if it is not available and vice versa.

In general, accessibility describes the potential opportunities (Hansen, 1959) and the potential for interaction and exchange (Litman, 2017). Moreover, from a transportation planning perspective, accessibility refers to the potential of an individual to reach opportunities (Preston & Rajé, 2007). While in transit domain, accessibility might be introduced as a combination of the physical access to/from the service and service coverage (Murray & Wu, 2003). Consequently, transit service accessibility definition should accommodate physical proximity (e.g. stop location, sidewalks, bike lanes, and service coverage), service multimodality (e.g. park and ride facilities, and transfers between transit modes), and service availability (e.g. service span and service frequency).

The literature of transit accessibility might be categorized into: (1) by-transit accessibility (BTA) and (2) to-transit accessibility (TTA) measures (Moniruzzaman & Páez, 2012; Xu & Yang, 2018). BTA refers to the ease of connecting origins and destinations through public transit and it is usually referred to as transit network accessibility (Hillman & Pool, 1997), regional accessibility (Yang, Zhou, Shyr, & Huo, 2018), or accessibility (Chowdhury, Zhai, & Khan, 2016). While TTA refers to the physical proximity to the transit service, which considers the built environment. TTA is usually named local accessibility (Hillman & Pool, 1997), access (Chowdhury et al., 2016), or location-based accessibility (Moyano, Martínez, & Coronado, 2018).

This paper adopts a more inclusive approach to evaluating the local accessibility of transit stops. In particular, our paper provides sound contributions, to the current literature as well as transit practitioners, which can be articulated across three main aspects: 1) In addition to the built environment, the paper encompasses service availability into a to-transit accessibility measure, 2) The paper introduces a transit Stop Importance Index based on the surrounding land use characteristics, 3) The paper measures stop utilization levels, and 4) Through the integration of importance and utilization, the paper assigns an improvement urgency level for each stop.

3 Methodology

3.1 Frequency-based Stop Accessibility

Taking into consideration physical accessibility as well as service availability at each transit stop assembles a more informative indicator for individual's ability to use transit service. Consequently, a more

representative to-transit accessibility measure should describe: 1) The ease of reaching transit stops through the built environment, and 2) The availability of transit service when reaching a stop. The proposed measure implies that a transit stop is only accessible, if and only if transit service is current at this stop (i.e. it describes the transit stop as a bulb that only shines when a transit service arrives). In other words, the proposed measure links transit stop utilization, *how frequent is the transit service at the stop*, to the built environment to form a to-transit accessibility measure, in a Frequency-based Stop Accessibility (FSA) measure. Consequently, the FSA for a stop j , and within time period t , is expressed as follows:

$$FSA_{jt} = SBE_{j,1km} \times SU_{jt} \quad (1)$$

Where $SBE_{j,1km}$, an indication for the built environment, is the density of sidewalks and bike lanes within a one-kilometre radius around stop j relative to the density of roads. SU_{jt} , stop utilization, is how frequent a bus stop j is being utilized in a time period t , considering all transit routes serving that stop. FSA indicates that a transit stop with a high utilization rate is more accessible than a stop with a low utilization rate assuming the same built environment. For instance, if a stop j with a very good built environment at time period $t(10AM:11AM)$ does not have any transit services, this stop will appear as not accessible at all according to FSA measure, $FSA_{j(10:11AM)} = 0$. The measure treats both the built environment and service frequency as equally contributing factors for stop accessibility.

3.2 Transit Stop Importance

Assigning a Stop Importance to each stop in a transit system allows transit practitioners to prioritise improvement plans and optimize service operation adequacy. The importance of transit stops varies according to the surrounding land use characteristics. Land use is a leading contributor to transit service planning because of its direct significant impact of ridership. Transit stops located near land uses with high trip generation characteristics (e.g. high population density neighbourhoods, universities, shopping malls, etc.) are more likely to be highly utilized by transit users and hence have a higher importance. While transit stops located near land uses with low trip generation characteristics are less likely to be highly utilized and hence have a lower importance. This paper proposes a stop importance index that considers the surrounding land uses characteristics (weights) and their actual proximity to the stop.

The characteristics of the surrounding land uses are considered through assigning a weight to each land use which reflects its importance based on an expert opinion survey (Eldeeb, Elmitiny, & Darwish, 2015; Eldeeb, Elmitiny, Darwish, & Idris, 2018), or assigning a weight to each land use, which reflects its trip generation characteristics. In this paper, the Institute of Transportation Engineers (ITE) trip generation manual (ITE, 2017) was used to assign a rate to each land use which reflects its trip generation characteristics on a weekday. These rates were normalized into a unified area unit and then assigned to the land use Geographic Information System (GIS) map to estimate land uses' weights.

The proximity of land uses (activities) to transit stops are considered through a distance decay function where adjacent land uses have more influence on stop importance relative to far land uses. Stop importance index utilizes a stepwise distance decay function considering a plausible walking distance of 0.4 kilometre (*Transit Capacity and Quality of Service Manual*, 2013), and a maximum walking distance of one-kilometre to transit stops (Iacono, Krizek, & El-Geneidy, 2008). Accordingly, the distance decay function represents how activities' weights (influence) vanishes when distance increases. A Stop Importance (SI) index for a stop j is estimated as follows:

$$SI_j = \sum_{i=1}^n w_i \times C_{ij}, \text{ and } c_{ij} = \begin{cases} 1 & d_{ij} \leq 0.4 \text{ km} \\ e^{-1.5d_{ij}} & 0.4 \text{ km} < d_{ij} \leq 1 \text{ km} \\ 0 & d_{ij} > 1 \text{ km} \end{cases} \quad (2)$$

Where w_i is the land use or activity i weight, and C_{ij} is the distance decay function from stop j to land use i . And, $e^{-1.5d_{ij}}$ was chosen to demonstrate the vanishing of activities' influence with distance increases. While n is the number of land uses or activities around stop j within a one-kilometer radius, and d_{ij} is the actual network distance from stop j to land use i .

3.3 Urgency levels of improvement and stop utilization

Comparing SI_j provides a rational to recommend the level of urgency for accessibility improvement for each stop. Towards that, SI and FSA were binned with respect to their 1st, 2nd, 3rd quartiles where values over 3rd Q indicates high levels of SI and FSA while values less than 1st Q indicates low levels. Stops with high SI and low FSA receive a high urgency improvement level, while stops with low SI and low FSA receive a no urgency improvement level. High urgency improvement level indicates a wide variation on SI and FSA levels (i.e. a stop with quite high transit supportive land uses but a low frequency of transit service and/or inadequate active transportation infrastructure). Towards that, the urgency of FSA improvement algorithm compared SI and FSA as shown in Figure 1. Additionally, comparing SI_j and the components of FSA_j , following the same approach, provides useful insights regarding stop utilization and SBE improvement urgency.

Stop utilization level describes how adequate a stop is being utilized relative to its importance. The more transit-supportive land uses are around a stop, the more transit ridership will be generated, and therefore more frequent transit services are needed. Consequently, stops with a high SI index are rationally expected to have more frequent services than stops with low SI index. Stop utilization levels range from strongly underutilized to strongly overutilized (Figure 2). The latter indicates a quite low SI and a quite high SU (i.e. implying the existence of more transit service than needed) while strongly underutilized indicates the opposite (i.e. implying the need for more transit service).

SBE urgency level of improvement describes how adequate the surrounding built environment of a stop proportionate to its

Figure 1 Urgency of FSA improvement algorithm

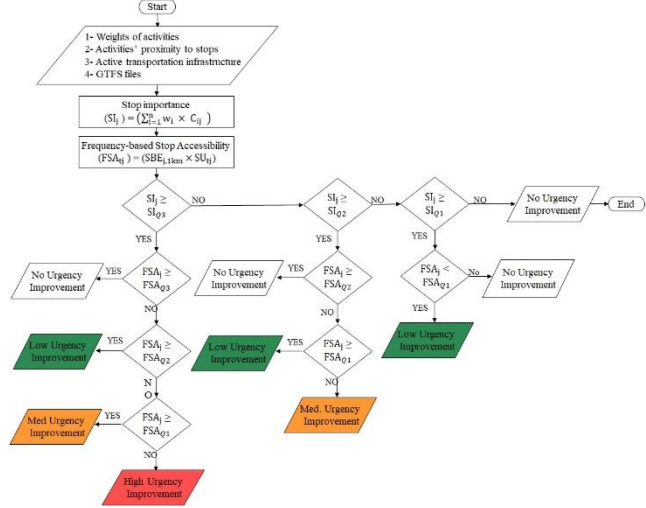


Figure 2 Stop utilization level algorithm

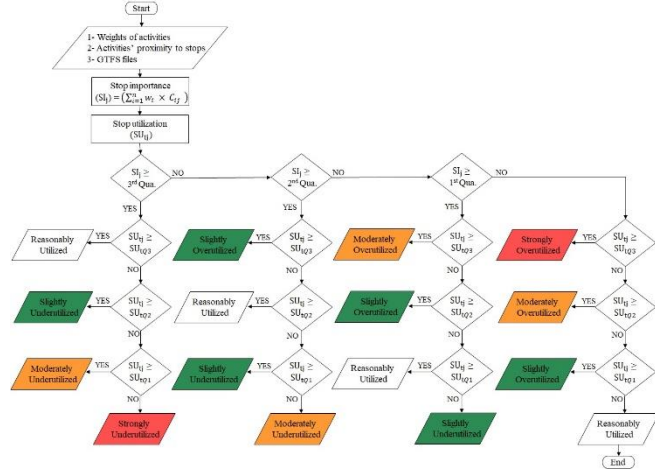
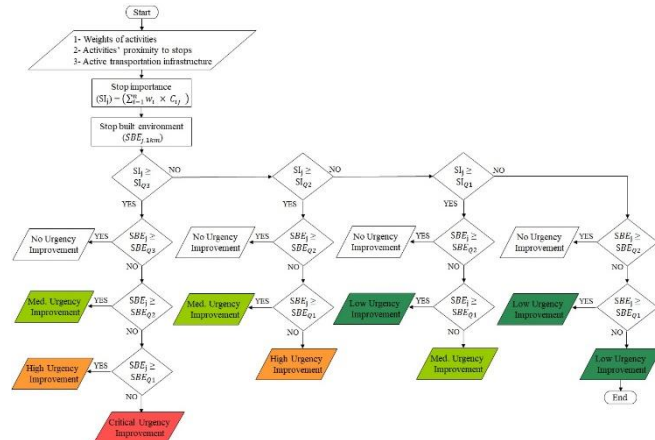


Figure 3 Urgency of SBE improvement algorithm



importance. Following the aforementioned analogy, stops with high SI are expected to have more adequate SBE than others. Improvement urgency levels range from no urgency of improvement to critical urgency of improvement (Figure 3). The latter indicates a quite high SI and quite low SBE (i.e. implying the dire need for improving SBE to support/promote transit use in high transit-supportive areas) while no urgency improvement proves reasonable built environment (i.e. indicating the consistency between SI and SBE and ensuring that $SBE_j \geq 2^{\text{nd}}$ quartile).

4 Case study and results

The City of Kelowna is located in the south of British Columbia, Canada. Kelowna is a medium size city and the largest city in the Okanagan Valley. Kelowna's population is around 127,380 people in 2016, and covers an area of 211.85 square kilometres (Statistics Canada, 2017). BC-Transit is the transit provider in Kelowna. Kelowna regional transit system operates a total of 28 routes, with 19 routes serving the city of Kelowna (BC Transit, 2017). All the datasets used in this paper, *land use*, *transit stops*, *roads network*, *sidewalks and bike lanes*, and *GTFS*², were obtained from the City of Kelowna open data catalogue (City of Kelowna, 2017).

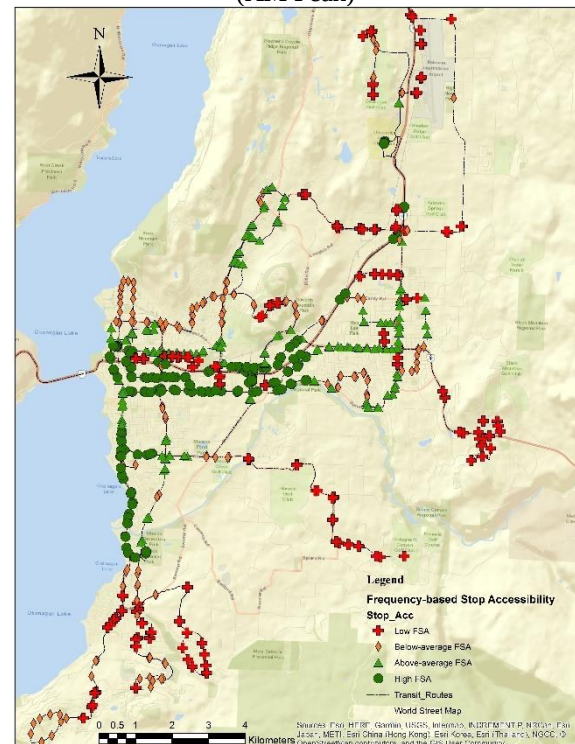
Using ArcGIS 10.6 along with the network analyst extension, SI and SBE were calculated for the whole network. Using GTFS data, the utilization of each stop during the AM peak (7:30 AM to 9:30 AM) was estimated regardless of the route numbers. Hence, FSA was calculated for each stop and then visualized as shown in Figure 4. FSA values are classified into four categories ranging from high to low FSA.

In general, transit stops with high FSA values are located near mixed land use developments and high-frequency transit corridors. While stops with low FSA values are situated in suburbs areas and/or on low-frequency transit corridors. As well, stops are being utilized by more than one transit route show relatively higher FSA values than others.

Precisely, the majority of stops with high FSA values are centred around routes 97-Okanagan and 1-Lakeshore/Downtown where high-frequency service, mixed land uses, and SBE are highly adequate. While stops around routes 8-University/Ok College rang from high FSA to above-average FSA considering SBE. In addition, SBE conditions cause FSA for the stops around routes 11-Rutland/Downtown, and 14-Black Mountain to vary from high, above-average, and below average.

Whereas the majority of stops with low FSA values are concentrated around routes 12-McCulloch, 13-Quail Ridge, 16-Kettle Valley, 15-Crawford, 17-Southridge, and 23-Lake Country. These routes serve suburbs and rural areas, where active transportation infrastructures are not adequate, with a relatively low frequency. Additionally, all stops around route 9-Orchard-Park/Downtown have low FSA values despite being in the downtown area.

Figure 4 FSA for Kelowna transit system (AM Peak)

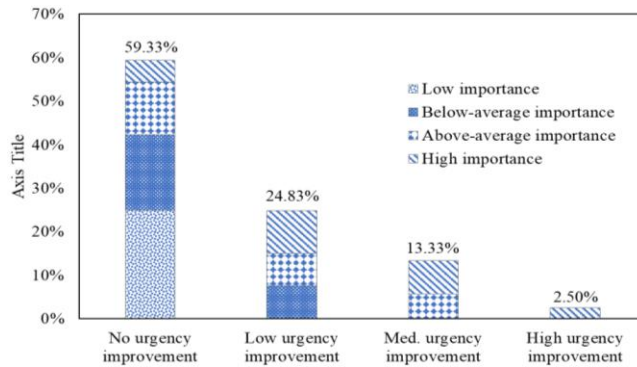


² General Transit Feed Specifications

Towards explaining the urgency level of FSA improvement for each stop, the urgency of FSA improvement algorithm related SI_j and FSA_j and proposed four urgency levels as shown in Figure 6. The results show that SI and FSA are consistent for Kelowna transit system with some exceptions in cases of a fairly high variation between SI and FSA. The distribution of urgency FSA improvement levels for Kelowna transit system is shown in Figure 5. It shows that around 60% of stops have their SI and FSA consistent and hence do not require urgent improvement. And around 25% of stops requires a low urgency improvement while only around 13% and 2.5% require medium and high urgency improvement, respectively.

Albeit identifying the extreme cases, these results do not explain the whole picture regarding the reason behind low FSA_j and/or inconsistency among SI_j and FSA_j .

Figure 6 The distribution of FSA improvement urgency levels



Stop utilization algorithm was applied to reveal a more detailed picture, as shown in Figures 7 and 8, regarding stops that require additional transit services to support the surrounding land uses, and the stops which have more transit service than needed.

The results show that around 25% of stops in Kelowna are reasonably utilized, which reflects a 25% consistency among SI and SU. While strongly overutilized and underutilized stops are about 4.5% and 4.7%, respectively. The latter indicates that 4.7% of stops have a quite high SI coupled with a low SU, and strongly overutilized implies that 4.5% of stops have a quite low SI and a quite high SU which might cause operation problems

Figure 8 The distribution of stop utilization levels

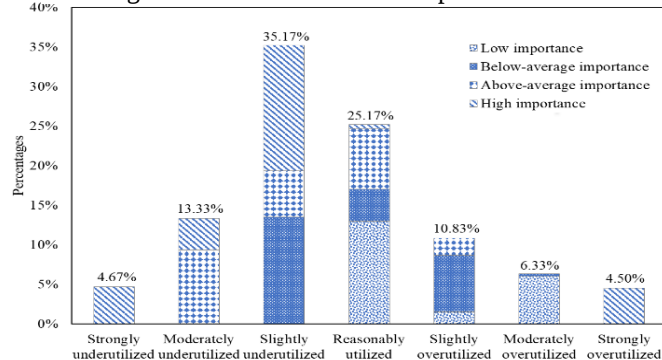


Figure 5 Urgency levels of FSA improvements

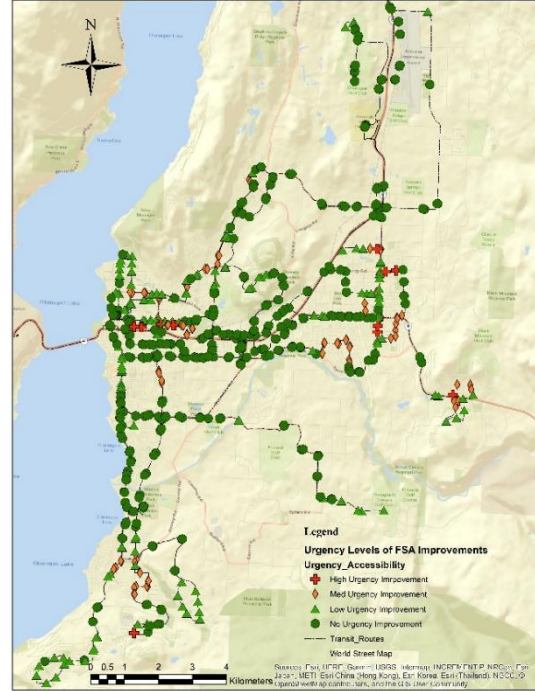
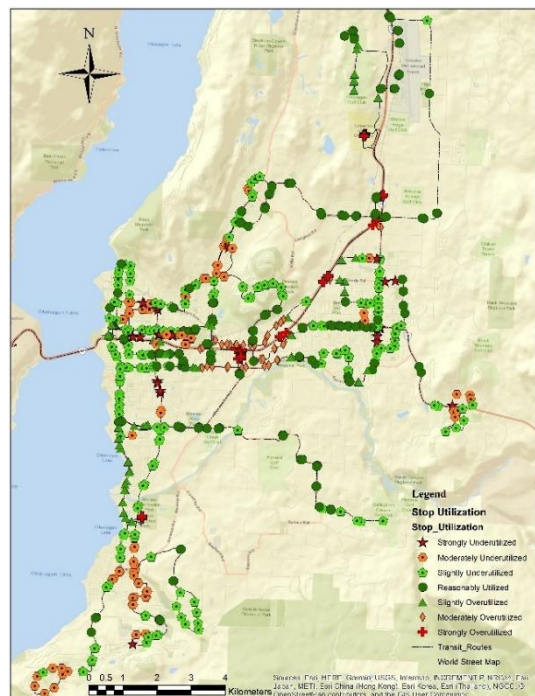


Figure 7 Stop utilization levels



(Eldeeb, Idris, & Parrott, 2018). The percentage of overutilized and underutilized stops are 21.66% and 53.17%, respectively.

SBE improvement urgency algorithm was applied to determine the urgency level of improvement for each stop's built environment with respect to the surrounding land uses, as shown in Figure 9 and 10. The results show that around 40% of stops' built environment does not require improvements as SI and SBE levels are consistent and/or $SBE_j \geq SBE_{Q2}$. While about 60% of the stops requires some improvements to the built environment. This indicates that 60% of the stops in Kelowna do not have adequate active transportation infrastructures with respect to the surrounding transit supportive land uses. Only 5% of the stops in Kelowna requires a critical urgency improvement to lessen the significant gap between SI and SBE that in turn affects transit ridership.

Figure 9 The distribution of SBE improvement levels

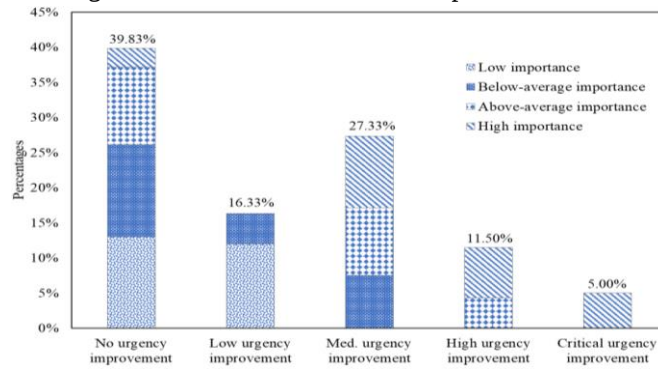
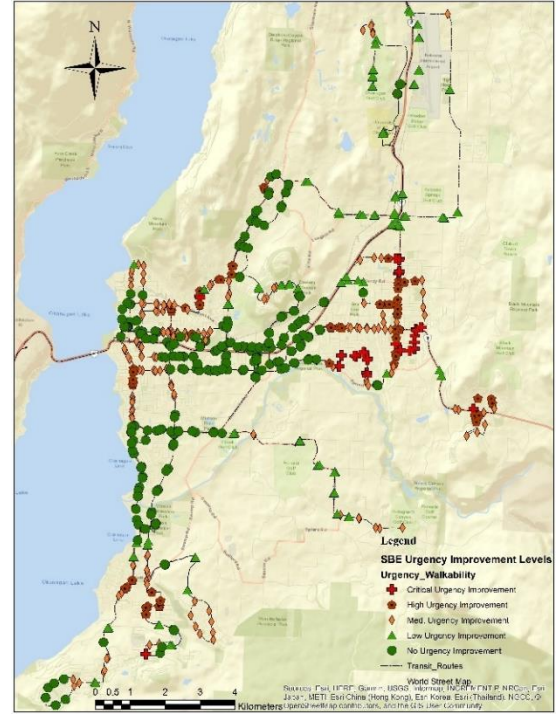


Figure 10 SBE Improvement urgency levels



5 Conclusions

This paper adopted a more inclusive approach to evaluating the local accessibility of transit stops. Firstly, the paper developed an FSA_{jt} index, which reflects the suitability of the surrounding built environment (active transportation infrastructures) of a stop as well as transit service availability at this stop for a predefined time period. Secondly, this paper proposed an SI_j index which reflects the importance of the surrounding land uses with respect to their trip generation characteristics and considering their actual proximity to the stop. Thirdly, the paper introduced three different algorithms through manipulating SI_j and FSA_{jt} as well as its components, SU_{jt} and SBE_j , to investigate each stop utilization level and to determine the urgency level of improvement regarding FSA_{jt} as a whole and the built environment for each stop.

The City of Kelowna Transit System was adopted as a case study. Using ArcGIS 10.6 along with the network analyst extension, SI and SBE were calculated for the whole network. Using GTFS data, the utilization of each stop during the AM peak (7:30 AM to 9:30 AM) was estimated regardless of the route numbers. The results showed that transit stops with high FSA values are located near mixed land uses and high-frequency transit corridors, and more likely are being utilized by more than one transit route. The distribution of urgency levels of FSA improvements showed that around 60% of stops have their SI and FSA consistent and hence do not need urgent improvement. Moreover, around 25% of stops need a low urgency improvement. While only around 13% and 2.5% require medium and high urgency FSA improvement, respectively.

Regarding stop utilization levels, the results showed that around 25% of stops are reasonably utilized. While the percentage of overutilized and underutilized stops are 21.66% and 53.17%, respectively. With respect to the urgency levels of SBE improvements, the results show that around 40% of SBE does not require improvements, while about 60% of the stops require SBE improvements.

The proposed methodology helps transit operators: 1) To evaluate stops local accessibility in an inclusive way by considering both spatial and temporal aspects, 2) To prioritize stops' FSA improvement plans with respect to stop importance, 3) To optimize transit service operation which might be through reducing service at a specific stop while increasing it at another based on stop utilization, and finally 4) To prioritize stops' SBE improvement plans.

6 References

- Barker, J. B., Alvarez, D., Barnes, R. L., Garber, C., Greene, S., Irwin, R. H., ... Rosenberg, J. M. (2003). *TCRP Report 88 - A Guidebook for Developing a Transit Performance Measurement System*. Transit (Vol. 5). Washington, D.C. Retrieved from http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_report_88/Guidebook.pdf
- BC Transit. (2017). Kelowna Regional Transit System. Retrieved November 29, 2017, from <https://bctransit.com/kelowna>
- Ceder, A., & Wilson, N. H. M. (1986). Bus network design. *Transportation Research Part B*, 20(4), 331–344. [https://doi.org/10.1016/0191-2615\(86\)90047-0](https://doi.org/10.1016/0191-2615(86)90047-0)
- Chowdhury, S., Zhai, K., & Khan, A. (2016). The Effects of Access and Accessibility on Public Transport Users' Attitudes. *Journal of Public Transportation*, 19(1), 97–113. Retrieved from <http://scholarcommons.usf.edu/cgi/viewcontent.cgi?article=1459&context=jpt>
- City of Kelowna. (2017). City of Kelowna - Open Data Catalogue. Retrieved November 29, 2017, from http://opendata.kelowna.ca/datasets?group_ids=02450113d1b24fc089ff4f827e29b8aa
- Dhingra, C. (2011). *Measuring Public Transport Performance: Lessons for Developing Cities*. Sustainable Urban Transport Technical Document (Vol. 9). Eschborn, Germany. Retrieved from http://www.sutp.org/files/contents/documents/resources/B_Technical-Documents/GIZ_SUTP_TD9_Measuring-Public-Transport-Performance_EN.pdf
- Ding, L., & Zhang, N. (2016). A Travel Mode Choice Model Using Individual Grouping Based on Cluster Analysis. *Procedia Engineering*, 137, 786–795. <https://doi.org/10.1016/j.proeng.2016.01.317>
- Eldeeb, G., Elmitiny, N., & Darwish, G. (2015). Developing Transit Suitability Map Using GIS and Analytical Hierarchy Process. *Journal of Intelligent Transportation and Urban Planning*, 3(4), 108–115. <https://doi.org/10.18005/ITUP0304001>
- Eldeeb, G., Elmitiny, N., Darwish, G., & Idris, A. O. (2018). Integrated Spatial Multi-Criteria Decision-Making Approach to Bus Transit Planning. In *Transportation Research Board 97th Annual Meeting* (p. 16). Washington DC, United States: Transportation Research Board. Retrieved from <https://trid.trb.org/view/1495192>
- Eldeeb, G., Idris, A. O., & Parrott, L. (2018). Agent-Based Approach to Modelling Bus Bunching and Dispersion Under the Influence of Demand Variability. In *Transportation Research Board 97th Annual Meeting* (p. 14). Washington DC, United States: Transportation Research Board. Retrieved from <https://trid.trb.org/view/1495889>
- European Committee for Standardization. (2002). *EN 13816 (2002). Transportation - Logistics and Services - Public Passenger Transport - Service Quality Definition, Targeting and Measurement*. European Committee for Standardization. Retrieved from [https://go.itdp.org/download/attachments/42598847/11\)UITP EN 13816 standard - Service Quality Definition, Targeting and Measurement \(EU 2002\).pdf?api=v2](https://go.itdp.org/download/attachments/42598847/11)UITP%20EN%2013816%20standard%20-%20Service%20Quality%20Definition,%20Targeting%20and%20Measurement%20(EU%202002).pdf?api=v2)
- Hansen, W. G. (1959). *Accessibility and Residential Growth*. MASSACHUSETTS INSTITUTE OF TECHNOLOGY. Retrieved from <https://pdfs.semanticscholar.org/ca2d/377bd85eac42ed1ac8271ac590a935e1444.pdf>
- Hillman, R., & Pool, G. (1997). GIS-based innovations for modelling public transport accessibility. *Traffic Engineering & Control*, 38(10), 554–559.
- Iacono, M., Krizek, K. J., & El-Geneidy, A. (2008). *Access to Destinations: How Close is Close Enough? Estimating Accurate Distance Decay Functions for Multiple Modes and Different Purposes*. Retrieved from <http://www.lrrb.org/PDF/200811.pdf%5Chttp://www.cts.umn.edu/access-study/research/6/index.html>
- ITE. (2017). *Trip Generation Manual* (10th Editi). Washington, D.C.
- Litman, T. (2016). *Evaluating Public Transit Benefits and Costs, Best Practices Guidebook*. Retrieved from <http://www.vtpi.org/tranben.pdf>
- Litman, T. (2017). Evaluating Accessibility for Transportation Planning Measuring People's Ability To Reach Desired Goods and Activities, (July 2017), 57. Retrieved from <http://www.vtpi.org/access.pdf>
- Los Angeles County - Metropolitan Transportation Authority. (2015). *Transit Service Policy*. Los Angeles, California, USA. Retrieved from http://media.metro.net/images/service_changes_transit_service_policy.pdf
- Mahmoud, M., & Hine, J. (2013). Using AHP to measure the perception gap between current and potential users of bus services. *Transportation Planning and Technology*, 36(1), 4–23. <https://doi.org/10.1080/03081060.2012.745316>
- Mahmoud, M., & Hine, J. (2016). Measuring the influence of bus service quality on the perception of users. *Transportation Planning and Technology*, 39(3), 284–299. <https://doi.org/10.1080/03081060.2016.1142224>
- MBTA. (2017). *Massachusetts Bay Transportation Authority Service Delivery Policy*. Greater Boston, Massachusetts, USA. Retrieved from http://www.mbta.com/uploadedfiles/About_the_TB/Board_Meetings/MBTA_Service_Delivery_Policy_2017_FINAL.pdf
- Mistretta, M., Goodwill, J. A., Gregg, R., & De Annuntis, C. (2009). *Best practices in transit service planning*. Report No. 21177772000. State of Florida, USA. Retrieved from <http://www.nctr.usf.edu/pdf/77720.pdf>
- Moniruzzaman, M., & Páez, A. (2012). Accessibility to transit, by transit, and mode share: application of a logistic model with spatial filters. *Journal of Transport Geography*, 24, 198–205. <https://doi.org/10.1016/j.jtrangeo.2012.02.006>
- Moyano, A., Martínez, H. S., & Coronado, J. M. (2018). From network to services: A comparative accessibility analysis of the Spanish high-speed rail system. *Transport Policy*, 63(November 2017), 51–60. <https://doi.org/10.1016/j.tranpol.2017.11.007>
- Murray, A. T., & Wu, X. (2003). Accessibility tradeoffs in public transit planning. *Journal of Geographical Systems*, 5(1), 93–107. <https://doi.org/10.1007/s101090300105>
- Preston, J., & Rajé, F. (2007). Accessibility, mobility and transport-related social exclusion. *Journal of Transport Geography*, 15(3), 151–160. <https://doi.org/10.1016/j.jtrangeo.2006.05.002>
- Statistics Canada. (2017). *2017. Focus on Geography Series, 2016 Census. Statistics Canada Catalogue no. 98-404-X2016001*. Ottawa, Ontario, Canada. Retrieved from <http://www12.statcan.gc.ca/census-recensement/2016/as-sa/fogs-spg/Facts-CSD-Eng.cfm?TOPIC=1&LANG=Eng&GK=CSD&GC=5935010>
- Transit Capacity and Quality of Service Manual*. (2013). National Academies of Sciences, Engineering, and Medicine. Washington, DC. <https://doi.org/10.17226/24766>
- Xu, W. (Ato), & Yang, L. (2018). Evaluating the urban land use plan with transit accessibility. *Sustainable Cities and Society*, 45(November 2018), 474–485. <https://doi.org/10.1016/j.scs.2018.11.042>
- Yang, L., Zhou, J., Shyr, O. F., & Huo, (Derek) Da. (2018). Does bus accessibility affect property prices? *Cities*, 84(June 2018), 56–65. <https://doi.org/10.1016/j.cities.2018.07.005>