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Evaluating the Accessibility of Bus Stop's in Addis Ababa City: A Case of Anbesa City Bus Service Enterprise Route 101: Tafo to Megengana

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Abstract

Decision on how many buses stops to provide along service routes significantly influence performance of the agency and efficiency of service provision to the community at large which makes accessibility analysis of bus stop locations necessary for a sustainable transport system. Unfortunately, bus stops have not been seriously dealt with in Ethiopia; hence the purpose of this paper is analyzing bus stop accessibility for users in the course of service. As doing so to better understand the service coverage taking bus stations as a point of interest route 101 of ACBSE with fixed stop patterns is selected and two cases are defined: (1) Base line scenario: the existing spatial distribution of bus stops and (2) Alternative scenario: proposed bus stop locations; Results verified that proposed change (about 8% of current stops) could gain in coverage by 7% of the total population of Addis Ababa city when compared to the baseline.

Keywords: Bus Stop Location; ACBSE; GIS, Accessibility

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1. Introduction

A key component of sustainable mobility is urban public bus transportation, which has many benefits over driving a private vehicle, such as less energy use, traffic congestion, and air pollution (Tammaru et al., 2023) Prior studies have highlighted the vital role that public transportation plays in attaining sustainable urban development (Zergas & Litman, 1997).

The accessibility of bus stops has a significant impact on the efficacy of public bus transit, even with its potential advantages. According to studies, bus stops that are strategically placed can greatly boost both public satisfaction and ridership (Li & Bertni, 2008, Huang & Liu, 2014, Furth & Mekuria, 2005). Nonetheless, little research has been done on the best places for bus stops in Ethiopia, especially in Addis Ababa.

By examining the accessibility of the current bus stop locations for Route 101 in Addis Ababa, this study seeks to close this gap. The results will be used in the development of alternate bus stop locations and the evaluation of their possible effects on population accessibility and service coverage. The findings of this study can guide Addis Ababa's bus stop design and optimization efforts and provide the groundwork for related projects in other Ethiopian cities.

2. Literature Review

Currently, public transportation financing and expansion is becoming highly reasonable to develop social justice. Hence, methods for evaluating the economic impacts of bus stops are a critical component of transportation planning and management processes, which can be performed from efficiency and equity objectives. Efficiency assumes that policies should strive to maximize social welfare while equity a highly subjective concept which assumes policies should ensure benefits and costs are spread in a fair way which makes it difficult to make judgments (Ambo, 2016; Immers & Stada, 2004; Litman, 2006).

Given the fact that public transportation plays a key role in ensuring equitable accessibility and all the components of bus stop design are important, it is usually specified in terms of spacing between stops or distance to stops which makes it an inherent tradeoff between the costs and benefits. Thus, it can be distinguished that there are many scenarios which will impact stop operations; for-example, as Huang and Liu (2014) argue closely spaced bus stops provide a short walking distance for passenger access with high operational costs and low efficiencies; when compared to large spaced stops that minimize travel time.

Thus, one of the key issues for locating bus stops is to understand the walking distance for equitable accessibility to distribute the benefits of transportation fairly. Thus, to balance efficiency and equity, operation costs should be reduced without impacting accessibility. In doing so Li and Bertni (2008), had derived expressions for an aggregate total cost function, including minimizing access cost which favors small spacing and minimizing riding cost which favors large spacing. The findings of (Li & Bertni) indicate that total costs of access and riding per unit length are convex and costs over longer trip length can be optimized by minimizing spacing per unit length.

Thus (A, S, & B, 2014) and (Adebola & Enosko, 2012); investigated distribution of stops in Nigeria Ilorin Metropolis and Ibandan north Oyo state respectively. Both authors bear similar approaches using questionnaire survey and inventory of existing stops using GIS. Exceptionally, (Adebola & Enosko) considered 8m shelter buffer away from carriageway, spacing

interval of 400m & 50m spaced contour map. The results of both authors confirmed enhancements in bus mobility require optimal locations are best achieved by harmonizing access with walking distances and adjacent land use.

The optimization of bus stops via consolidation has been the subject of numerous research. To evaluate the effect of stop deletion, (Furth & Mekuria, 2005) examined demand and stop service regions in Boston. (Xuebin, 2010) reduced redundancy while preserving accessibility to improve stop positions in Wuhan. In 2013, (Shrestha & Zolnik, 2013) conducted an analysis on the effects of stop deletion on walking lengths and air quality in Virginia in order to investigate the trade-offs between equality and emissions.

While walking distance is often used as a proxy for equitable accessibility, its limitations in capturing broader equity dimensions are recognized (Immers & Stada, 2004; Litman, 2006; Tyree, 2010). Litman (2017) distinguishes between horizontal and vertical equity, emphasizing the importance of considering diverse user needs and abilities.

The literature presented thus far on this subject, it can be shown that purpose of stop optimization is twofold, (1) equitable accessibility to make the service both horizontally and vertically equitable for all users, particularly to the special needs of users, seniors and passengers with disabilities (2) optimize costs and create acceptable option to transit commuters, agencies and authorities associated with the system. In doing so it is also observed that GIS go hand in hand with analyzing bus stops.

Overall, these cases support the view that even though there are many approaches to conduct accessibility analysis which appear to be relatively different, they turn out to have one goal optimizing costs and conferring to provide acceptable option to all participants of the system. Hence, from the literature it can be inferred that in-cooperating the various variables in decision making process plays a pivotal role in reaching an optimum solution which balances the tradeoff between efficiency and equity.

Bus Stop Location

Bus operating speed is largely determined by stop spacing, which has an immediate effect on service quality and cost. Time is lost at every stop because of acceleration, deceleration, and passenger boarding and alighting. Bus speed average decreases when stop frequency is increased, but accessibility is improved (COTA, 2014; Eshete, 2015; TRB, 2000).

The amount of time a bus spends at a stop, or dwell time, adds a lot to the overall trip duration. Increased passenger delays and discomfort are caused by longer dwell durations (Tsegaye, 2018) . At an average of 25.64 seconds, dwell time in Addis Ababa accounts for 14% of overall trip time (Tsegaye, 2018).

What stands out from aforesaid literature is that; bus stop spacing can be understood as a tradeoff between speed and access which makes accessible and efficient services the vital features of well utilized public transit systems, so optimum spacing of stops that will have positive effects on quality of service as well as operational effectiveness, reliability and efficiency; characterized by attractive operating speed and travel time are critical (COTA, 2014; Higgins & Audirac, 2008; Mihretie, 2013; RTA, 2015). In doing so; Eshete (2015) argues optimal spacing between fixed-stops should be 0.8 km whereas on demand-stops per 1.6 km based on previous research. Further, different agencies recommend diverse bus stop proposition that spacing will be governed by a mixture of variables like density,

available alternatives, and frequency of side road accesses, fixed-stop spacing distance, safety, public input and efficient operations.

On the other hand, the two widely accepted research programs in the transit industry namely TCRP and NCHRP found out that the range of spacing practiced is between about 90m and 800m respectively which confirm a moderately uniform spacing should be provided except in few points where there are acceptable conditions. Despite (Adebola & Enosko, 2012) recommends spacing must not be less than 300metres interval in any case (Furth & Mekuria, 2005) argues that, the tradeoffs involved do not lead to simple, generalizable stop spacing guidelines such as "optimal stop spacing is X meters" Thus, periodic studies should be conducted to assess the local conditions which suit both passengers and transit agencies to concentrate passenger movements among fewer stops, thus reducing time lost from deceleration, dwell, and acceleration.

3. Methodology

An economic impact is any change in the amount flow and/or distribution of money due to changes in the production, distribution, and consumption of goods and services. Analysis of economic impact is done to support decision making, to determine the value of a policy, project or program, and to measure the magnitude and duration of the economic effects (Litman, 2006). In this regard transportation is an essential part of the economy and changes are likely to impact the economy in some way. Taking this fact many studies claim that transportation funds are the life blood of the economy and see transport as engines that fuel economic growth. Consequently, determining whether a given transportation investment or policy makes enough of an impact to earn the description of "economic engine" requires careful data collection and analysis.

4. Impact Characterization (Influence, Scope, Magnitude, Scenarios)

Public bus transit is notable for its uniqueness with its frequent interface with commuters at bus stops which necessities the need for achieving a maximal coverage of given demand points with a minimal number of bus stops. Thus, periodic audits simultaneous with economic evaluation should be made to ensure overall transit compatibility with quality of service expected by commuters, objectives set by planners and for continuous improvement of industry practices. Unfortunately, it has been found out there is often a trade-off between equity and efficiency objectives. To evaluate these perceived compromise between equity and efficiency with in local setting; which is likely to promote increased utilization of public transit, economic impact analysis (EIA) in context of this paper is done to unveil how bus stop will impact the primary recipients of public transit, community and agency in selected major routes; the impacts characterized and investigated in the course of service are direct impacts related with the service accessibility and road user effects; indirect impacts include the environmental effects on the community at large.

Taking these lessons from evaluation approaches cited in the literature, pertinent documents at the time of the study were identified to assess the accessibility of bus stop locations as they exist today, proposed change to spatial distribution of stations to find best-possible scenario.

Prior studies have also underlined the importance of identifying areas with employment and population densities which are likely to generate considerable transit use; some of the noticeable CBD in Addis Ababa city include Hayahulet, Kazanchis, Mexico, Aratkillo, Piazza and

condominium housing sites like Yeka-abado, Ayat-tafo, Semit and Jemo (to name a few). And yet, the cities 10th master plan also recognizes city centers across eight locations, including the National Theatre, Cherqos, Filwoeha-Mesqel square, Lagare, Kazanchis and Churchill. Since the case study is based on ACBSE fixed stop bus service routes that link densely populated suburbs located in the outskirts of the city with the inner-city central business districts (CBD) like Aratkillo, Piazza, Lagare, Megenagna, Kotebe and Ayat, monthly financial and ridership performance reports compiled by ACBSE is used to evaluate routes efficiency and identify major routes for the year 2008 and 2009EC.

The criteria to select these routes were as follows: first intra-city service routes were identified, and routes were then organized by revenue generated. Yet, ACBSE bus performance reports compiled based on ticket sales data appear to support the assumption that there may be situations allocated buses may not provide service. Thus, three routes operating along the commonly known and specified central business districts in the 10th master plan which serve a noticeable yearly passenger were selected based on the ridership performance of ACBSE. The identified routes of interest for this study are route number 101 which play a key role in the provision of public bus transit to peoples resettled in condominium buildings, central business districts and densely populated areas in Yeka and Bole sub cities. See Figure 1 for study area location in Ethiopia, Addis Ababa.

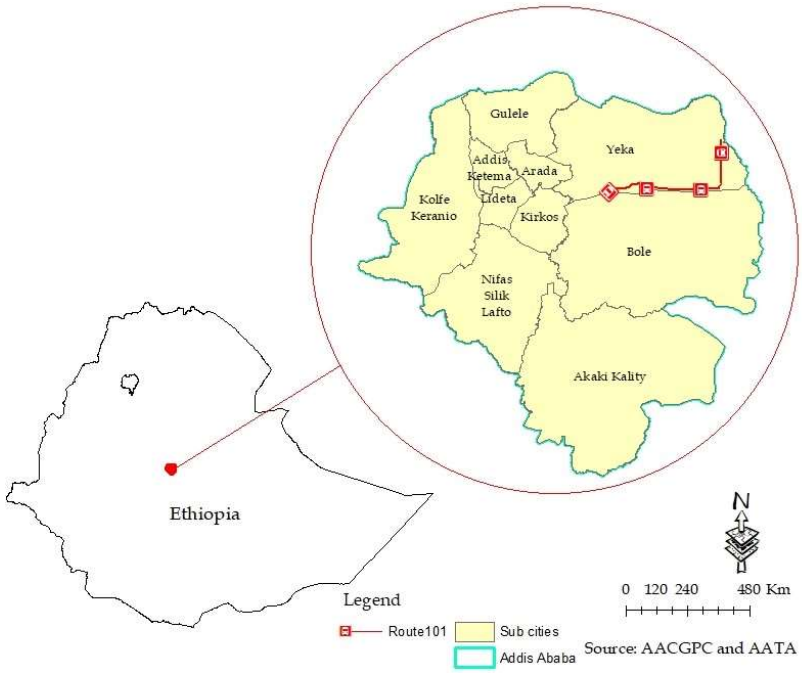


Figure 1 Study area location in Ethiopia, Addis Ababa
Source: AACGPC and AATA

Thereby for the purpose of evaluation, two analysis scenarios are defined as (1) base line (i.e., existing condition) and (2) alternative (i.e., proposed change). Then relative assessment of benefits, magnitude and value of alternative scenario is compared in relation to the base line scenario to identify the best possible scenario that can be considered good.

5. Analysis Scenario

Extensive literature has shown that ACBSE was established with the intention to provide public transit service with great responsibility to serve the public and improve/upgrade its service to satisfy its passengers' need as well as to cut costs at large. To do so provision of optimum bus stop spacing is a stimulus that provides a step forward to that goal by maintaining the tradeoff between operating agency costs & public welfare. Although all conflicting interests may not be fully satisfied, this paper seeks to characterize the existing impacts versus the predicted impacts of an alternative being considered as a good balance of possible concerns and feasible courses of action. A baseline analysis scenario is defined as the existing spatial distribution of stops, to measure the net changes that would have occurred in the absence of the change.

In addition, literature suggests that removing and/or consolidating stations that are not within a certain spacing threshold will offer improvement in operations, coverage and emissions. Indeed, as it has been noted in (Alam, 2015; Shrestha & Zolnik, 2013), spacing bus stops at rigidly regular intervals not only will result the need for accessibility improvements, but also result in inconvenient positions, which makes itself insufficient to balance all opposing issues. Therefore, it is appropriate to consider various factors like transfer opportunities, accessibility and safety when placing bus stations.

a) Classifying Existing Stations

Similar with Huang and Liu (2014), existing stops are classified as follows:

- Ordinary stops: stops that are at a lowest level located to ensure appropriate spatial coverage of bus stops.
- Key stops: topologically important stops that may serve as transfer centers for bus trips.
- Connection stops: stops that link bus transit to other transport modes, such as rail stations and road intercity transport, and major activity sites.

To validate whether existing stations are properly located have been overlaid on accessibility maps to identify stations, which have either overlapped zone of influence or gaps.

b) Formulate Alternative Spatial Distribution of Stations

Location is a key factor leading to the success of bus stations in supplying a high-quality service to the community at low cost (i.e., time or distance) when a suitable location is chosen. Given bus stop facilities supply access to transportation and a set of demand points consume them, the goal of location-allocation is to locate facilities in a way that supplies the demand points most efficiently. There are so many types of location-allocation, which offer different problem. To answer specific questions for the case of these research, the problem type is to maximize coverage within certain walking distance.

In cases of connection stops, they are kept providing access when there is a need for transfer opportunities between inter-city and intra-city transportation modes. Thus, stations with following conditions were found and red flagged to be removed/ consolidated from existing spatial distribution when there are service overlap stations are consolidated/removed.

To do so Distance Constrained P-Median Problem (DCPMP) is selected. A major advantage of DCPMP is that it reduces the current number of bus stops in order to promote faster transit speeds and greater geographic coverage ensures that all areas that are provided suitable access by the

current location of bus stops continue to receive suitable access (Challuri, 2006). The p-median problem involves the location of a fixed number of facilities in such a manner that the total weighted distance of all users assigning to their closest facility is minimized. By minimizing weighted distance, accessibility is maximized; which was first defined by (Hakimi 1965) according to (Challuri, 2006).

According to (Challuri, 2006), Hakimi defined the p-median problem on a network of nodes as a place of demand & potential facility location and arcs which represent transportation or accessibility linkages. Thereupon Hakimi proved that there existed at least one best solution to a network p-median problem that consisted entirely of nodes of the network with no restrictions on the distance that a user (demand) must travel to a facility. In reality, users travel to facilities decays as the distance to facility increases so p-median problem should be constrained by limiting the possible assignment of user (demand) to only those facilities that are within certain distance from the demand points.

Thereupon the distance constrained p-median problem, proposed in Murray and Wu (2003) cited by (Challuri, 2006) is used. The model is formulated as Eqn. 1:

$$Minimize\ Zi = \sum_{i} \sum_{j \in N_i} a_i d_{ij} z_{ij} \qquad (1)$$

Subject to:

$$\sum_{j \in N_i} z_{ij} = 1 \quad \forall i$$

$$z_{ij} \leq X \quad \forall i, j$$

$$\sum x_j = p$$

$$x_j = (0,1) \ \forall j$$

$$z_{ij} = (0,1) \ \forall i, j$$

Where:

Z = total weighted distance of route 1

i = index of ridership service areas.

j = index of potential transit stops (entire set denoted j).

p = number of stops to be maintained.

ai total weighted distance of route i.

Decision Variables:

$$x_j = \begin{Bmatrix} 1\ if\ transit\ stop\ j\ selected\ to\ remain\ on\ the\ route \\ 0\ other\ wise \end{Bmatrix}$$

$$Z_{ij} = \begin{Bmatrix} 1\ if\ transit\ stop\ i\ assigned\ to\ transit\ stop\ j \\ 0\ other\ wise \end{Bmatrix}$$

The aim of the DCPMP, Equation 3 6, is to minimize the total weighted assignment of potential demand to its nearest sited transit stop. The use of dij enables the model to account for differing levels of local accessibility to stops. Constraint (2) requires potential ridership demand in each area to be assigned to a transit stop within the suitable coverage standard. This constraint ensures that all potential demand for services is found within the acceptable access standard. Constraint (3) prohibits assignment to a stop unless that stop is sited. Constraint (4) stipulates that p stops are to be found. Finally, integer restrictions are stipulated in constraint (5).

Immediately to propose proper and feasible improvement measures (i.e., consolidate, remove or add), it is assumed that potential demand is equal to the total population of a census block. Further to limit possible assignment to stops that are within the access standard, governmental goals put forward by AACGPC which is "to reduce distance to public transit to 500 meters" (i.e., Ni).

To define the demand points, parcel polyline was converted to polygon using 'feature to polygon' route catchment then parcels with in 500m catchment area from the route of interest are extracted using 'clip' tool and intersected with census data, followed by calculations for respective areas and parcel populations in the attribute table. Then using 'feature to point' parcel centers were obtained, chaining the overall geo-processing chain of commands (Parcel population centroid model).

Then DCPMP analysis is made on ArcGIS 10.5 to do so location-allocation layer is created that stores the inputs, parameters, and results for a given location-allocation problem using respective route network dataset in Network Analyst toolbar location-allocation layer is created. When a location-allocation analysis layer is created, it shows up in the Network Analyst window along with its six network analysis classes Facilities, Demand Points, Lines, Point Barriers, Line Barriers, and Polygon Barriers.

Subsequently the Bus stop as facilities with different scenarios and Catchment area parcel centers as demand points datasets were loaded:

Scenario 1: Base Case Facilities as 'Candidate' p Unconstrained

To confirm station removals which have a service area problem (i.e., gaps and overlaps) and determine facilities that may be part of the solution the existing spatial distribution of stations have been analyzed by use of the parameter p.

Scenario 2: Modified Base Case & Candidate Facilities with p Constrained

In reality passengers are sensitive to elimination of service (i.e. bus stops) where as the number of stops (i.e. p) increases, the average travel distance to one's closest stop decreases, henceforth to balance the trading off travel distance and geographic coverage which could minimize the adverse impact of elimination the optimum number of stops to maintain service efficiency through fewer stops for respective route is determined by dividing route by 600m spacing and rounded down, which resulted in route 101(13.7/0.6= 22 stops) for analyzing base case.

After the removal of redundant stations, the resultant stops are defined as a 'modified base case'. In the meantime, candidate bus stop locations are generated using a bus stop spacing of 600m which is compliant with international and developing world practice for iterating the analysis in different scenario and introduce stations when there is service gap from the candidate sites. For the case of these existing stations which are kept are defined as 'required' facilities where are the generated candidate sites are defined as 'candidates.

Supplementary, to keep access within 10 minutes (i.e., which is about 540m) to a bus stop 'demand to facility' is selected with traversal cost along the elements of the network as length. Furthermore, the problem type is selected as 'Minimize Impedance', though 'Minimize Impedance' reduces the overall distance the public needs to travel to reach the chosen facilities, the minimize impedance problem without an impedance cut-off is ordinarily regarded as more equitable but in-efficient for locating bus stop. Thus, to maximize access and geographical coverage while keeping operator efficiency impedance cut-

off is defined as 500meters, with a limit on number of facilities and a linear transformation with an impedance parameter of 1 is used. After creating a location-allocation analysis layer, the required network analysis objects are populated, and setting analysis properties shown above, the solution for the location-allocation problem is determined by solving a location-allocation problem, which results in the appropriate output fields of the network analysis objects.

Subsequently the results are inspected by looking at the properties of the facilities and lines to verify station removal decisions. Then all solution facilities for the problem are exported to geo-database as 'optimal facilities' classified in to ordinary, key and connection to find accessible population and make comparisons against the baseline scenario, overlaid on the results of suitability to determine improvements.

6. Space-Time Accessibility Analysis in GIS

It has been noted in literature that, GIS have a great reputation to organize and visualize spatially-oriented database containing multiuse information's collected from various sources with different themes to support answering questions in terms of location, condition, trends, patterns, modeling, quantities, densities and proximity (Eck, Collura, & Aultman-Hall, 2004; Gabre, 2016). As a result several researchers have also utilized GIS to evaluate bus stop design in particular include (Adebola & Enosko, 2012; Furth & Mekuria, 2005; Furth & Rahbee, 2000; Huang & Liu, 2014; Pulugurtha & Vanapalli, 2008; Xuebin, 2010).

According to many scholars, the major advantage of GIS is it make it possible to develop interrelated maps, organize geographic information and find spatial relationships between datasets. Therefore, despite there are so many GIS tools out there ArcGIS 10.5 was selected due to its availability and analytical capability of emulating the widest range of 'what if' scenarios with easy interface. The GIS framework is structured to evaluate the spatial and temporal accessibility of public transit services in Addis Ababa further details and technical specifications, please refer to **Error! Reference source not found.**. The framework leverages ArcGIS 10.5 and its network analyst tools to analyze the accessibility of bus stops within a specified walking distance. The key components of the framework include:

- Data preparation & pre-processing: spatial data, including road networks, bus stops and population distribution were collected and prepared for analysis.
- Tool development: Custom geo-processing models were created to automate repetitive tasks and improve efficiency.
- Area of interest definition: A buffer zone was created around the study routes to define the area of interest.
- Service area analysis: Network analysis was used to calculate service areas within a 10-minute walking distance from bus stops.
- Population analysis: Population data were intersected with service areas to estimate the accessible population.
- Space-time accessibility evaluation The framework assessed the potential impact of proposed transit improvements on accessibility.
- By combining these components, the framework provides a valuable tool for understanding the current state of public transit accessibility in Addis Ababa and informing future planning decisions.

7. Results and Discussions

This section enumerates the results and discusses the main findings. It starts by

discussing the spatial distribution of stops, vehicle operating cost accessible area, emission rate and emission control cost along the selected route of interest in the base case and proposed scenario.

Baseline Scenario

As mentioned in the literature review, ACBSE is the oldest operator that has undergone a lot of changes despite the financial constraints. However, state owned ACBSE still takes the major share of the market by operating in 124 routes through about 1440 fixed stops distributed in inner city and the surrounding suburbs (AATA, 2016; ACBSE, 2016; Eshete, 2015). Further investigation of stop spacing in the current study showed that it ranges from 100m to 1.2 km. As it is depicted from the chart in Figure 4 it is notable that distribution of distance between stops in any route is inconsistent, but in most cases, it ranges from 300-600m which may be attributed to a lot of reasons.

The identified routes of interest route number 101 have 23 stops spatially distributed in 13.7km of the route and the CBD in the route include Megenagna and Ayat with the smallest bus stop spacing of 300meters, and the highest of 1,100 meter; with average passenger in-vehicle travel time of 43 minutes which was obtained from ACBSE, however it was observed that they have a reliability problem. Moreover, the findings of research done by AACTA (2017) showed that the average waiting time is 1 hour and 26 minutes, which is consistent with findings (Eshete, 2015). Hence it is possible to hypothesize that ACBSE has a reliability problem which may be attributed to frequency issues.

Although the spatial distribution of bus stops is mainly linked with the distribution of housing, working, shopping, and other public service activities, the distribution of stops are inconsistently distributed without any formal guidelines. Yet, the distribution is tailored to serve high density population areas as origin of trip and central business districts as destination. Moreover, to serve a mixture of land uses which create considerable transit use like social and economic activities along the route contact points to load and unload passengers are placed.

Further investigation of the spatial distribution of stops and existing land use is also made however no correlation is found. In the meantime, stops are rubber-sheeted (i.e., overlaid) on the road network as shown in, to identify the type of stops on the route. Despite there being a total of 58 stations in the s study routes, 95% of them are on-street configurations. The reason behind monopoly spatial distribution of on-street stops is not clear but it may have something to do with lack of consideration of bus stop to the following traffic besides the road hierarchy along the routes is arterial streets. (See Figure 4).

Alternative Scenario

The significance of having suitable locations for a bus stop is recognized as a crucial element in the drive to improve the quality of public transit. As doing so to account for the fact that some factors have more importance in the suitability model, the datasets were weighted as they represent different geographical realities and consequently affects the location of the new stops in a unique way. In response, determination of potential sites for bus stop locations has been investigated using GIS to formulate an alternative that combines safely integrating with built-in environment and maximize total accessible population in the service area. To carry out this goal imagery data is used to see what exists on the ground that might not have been accounted for.



Figure 4 Base Case Spatial Distributions of Bus Stops

In response to this, data revealed that the street networks provided steer the flow of commuters to existing stations safely and stations do provide access to public facilities which shows that they were appropriately located. While this is the case many of the solutions are rooted in the decision of bus stop spacing; this is because spacing plays a pivotal role in enhancing service area, provision & quality in terms of optimum walking distance and facilitating transfer opportunities.

In the meantime, the average bus stop spacing in the routes 101 fall within the range 400m to 600m which is compliant with international and developing world. Thereupon location-allocation analysis is made to minimize impedance using P-median constrained problem the results of the analysis witnessed 4 ordinary stops should be eliminated in route 101, 3 ordinary stops were newly introduced, which make up the small percentage of changes in the average spacing before/after to be 596/623m. Further the resulted spatial distribution is mapped as shown in Figure 5, which shows the loss of stops means that residents provide a room to walk to the next nearest stop while the introduction of new stops maximizes the service coverage that in-turn reduces the walking distance.

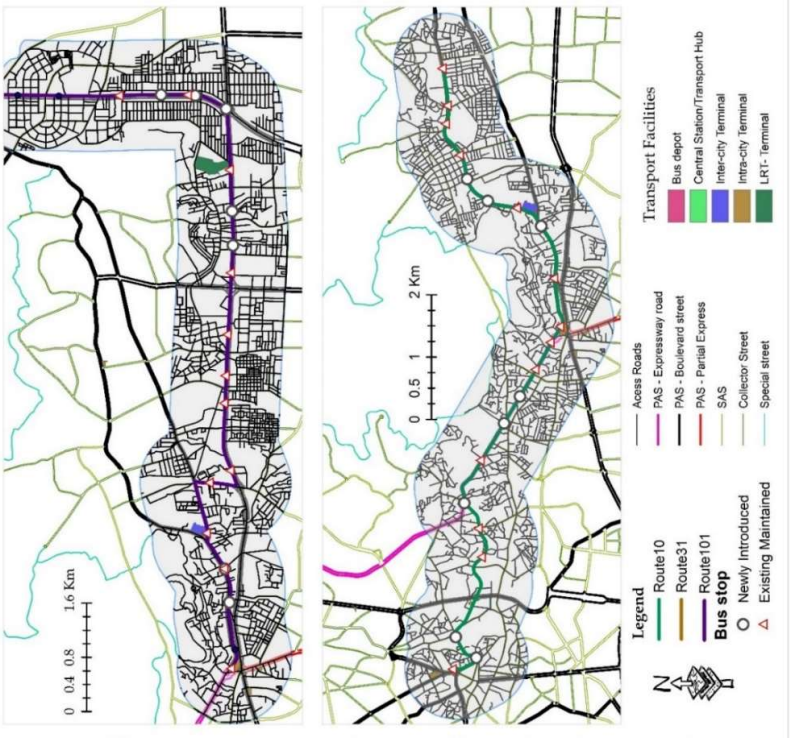


Figure 5 P-Median solution set spatial distribution of stops

Space-Time Accessibility of Bus Stops

Most passengers enter a transportation mode with intention of accessing their desired location in vicinity; so, the lesson seems clear mass transit stations need to be placed in a reasonable walking distance. Unfortunately, in reviewing the literature, retrieved research done in local context has not treated walking distance in much detail. For example (Taye, 2016) paper which focuses on

accessibility of AALRT has been more useful if his research considers service area within the actual street network rather than using buffer approach to determine the service extent of stop. Moreover (Mengistu, 2013) will have been more useful if the paper had in cooperated the effect of stop spacing which influences walking distance in his study which might be due to limitations of readily available GIS dataset which was also the challenge of the current study.

Though how to balance an opportunity to increase physical activity of transit user's and keep accessibility at the same time is a great question. In response to this research like (Furth & Mekuria, 2005) have explained the usefulness of accessibility analysis within actual street network. In doing so 500m walking distance from facilities in the street network is used for network analysis; the results of the service area as shown in Figure 4 16 revealed that not all the areas where routes were passing through have access to the bus stops, have service area have overlaps and gaps.

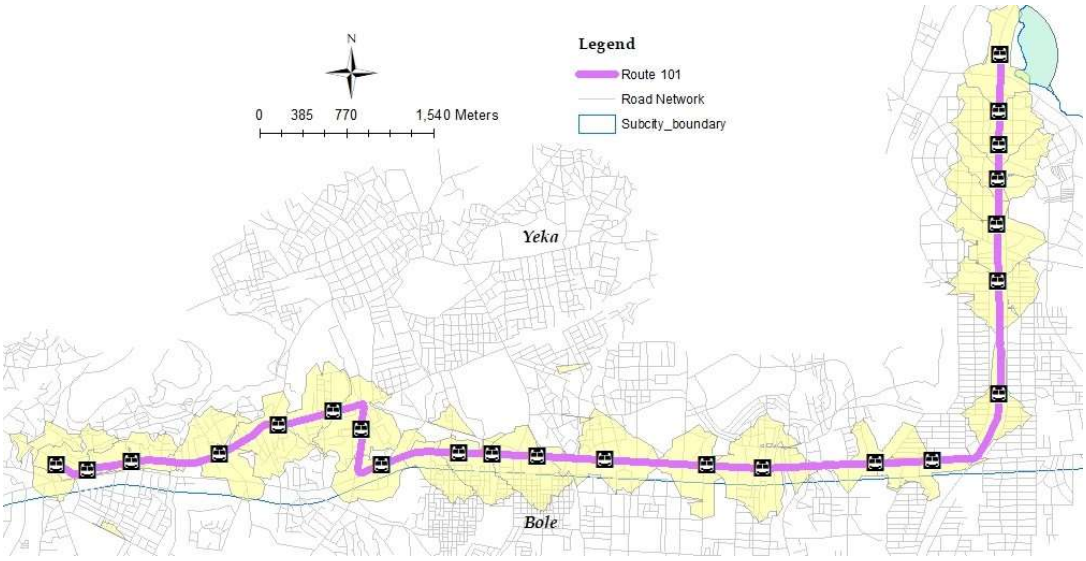


Figure 6 500m Service Area through Network Analyst and Buffer

Results from a query between accessibility map polygons (i.e., resulted from buffer and network analyst) and population census data when the service coverage is within 500m catchment from bus station showed that the accessible population within 5 and 10-minute walkway along the street network is estimated. As shown in Figure 6 the total accessible population for route and 101 with 5-minute threshold on street network with the alternative scenario accounted for a 9% drop. Similarly, the accessible population with 10-minute walking threshold for route 101 improved by 32% over the base case scenario. From the results it is evident that, the removal of selected existing stations in the alternative scenario has positive impact on maximizing accessible population; the relative net benefits associated with alternative scenario; and accessible population in routes of interest with 10-minute walking threshold

for routes 101 improved 32% over the base case scenario, the gain in coverage due to elimination and addition of bus stops is large (7%) of the total population of Addis Ababa City. Figure 6 Accessible populations in the service area.

8. Conclusions

This study has examined the economic impact of bus stop spacing on the Addis Ababa City Bus Service Enterprise (ACBSE) routes. By comparing a baseline scenario (existing spacing) to an alternative scenario designed to optimize accessibility, it has identified the alternative scenario significantly enhances accessibility for pedestrians, with a 32% increase in the population within a 10-minute walking distance of bus stops

These findings highlight the importance of carefully considering bus stop spacing to optimize public transit systems. While the ideal spacing may vary based on specific route characteristics and local conditions, the results demonstrate that strategic adjustments can significantly improve accessibility and economic efficiency. Further research is needed to delve deeper into the specific benefits and quantify their economic impact.

Therefore, to improve the overall effectiveness of the ACBSE, it is essential to re-evaluate the spatial distribution of bus stops and implement evidence-based solutions that prioritize the needs of passengers and the broader community benefits.

9. Recommendations

The issues raised in this paper point to the importance of evaluating accessibility on actual street networks that involve commuters walking to reach the nearest bus stop. Hence, continuous efforts are needed to locate stations by investigating how far people can comfortably walk to access bus stops and placing them at acceptable walking distance that in-turn elevate the attractiveness of mass transit. A reasonable approach to tackle this issue could be via considering multiple variables which play a part in decision making process with a key priority on walking distance to access transit using approaches such as those detailed in this paper.

Since using fixed route transit typically involves walking from and to transit stops, which necessitate the need for walkway connection besides the role of transit in increasing physical activity by the public daily is a widely recognized to reduce serious health problem in Addis Ababa. To do so, a proper walking environment is essential for encouraging the community to walk as a daily routine which in turn has a positive health effect. Meanwhile, despite it is not common in society to pass someone with physical disability, transportation system should be strategically integrated to form an effective pathway with due consideration of peoples with physical disabilities; since benefits to disadvantaged people often provide relatively large increase in social welfare and productivity, (Litman, 2006) therefore service access and mobility determines horizontal equity. In the meantime, it is an unfortunate fact that transit routes serving most of the population will likely perform better in cost benefit analysis. Thus, in order changes don't extremely impact riders with mobility challenges such as seniors and physical disabilities from using fixed-route bus services and enquiring additional costs it should be tested and monitored on a small-scale.

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Appendix 1. GIS Framework

1. Data Preparation

The following pre-processing actions are done: first the projection system for the spatial data is defined as Adindan_ UTM_Zone_37N. Following a serious examination of data's pertinent to the study routes and a significant cleaning, pre-processed data's were kept under a personal geo-database as feature datasets, grouped together with related feature classes for instance case study routes and, bus stations are grouped under ACBSE routes and bus stops respectively to bridge data exchange when geo processing tools or in-house built models require input or to store output spatial and non-spatial data generated within a separate container to work with a single window.

2. Tool Development

Then, for the purpose of analysis ArcGIS 10.5 is used, in fact some of repeated GIS operations take considerable processing time which necessitates the need for automating geo-processing. Henceforth, these batch jobs are programmed through ArcMap as a gateway to build re-usable and self-documenting models that systematize and create efficient geo-processing workflow. The decision to use model builder is based on its easy-to-use

feature to automate, iterate and/or show the sequence of complex tools chained together, perform analysis alongside with managing dataset and producing accurate outputs as a result.

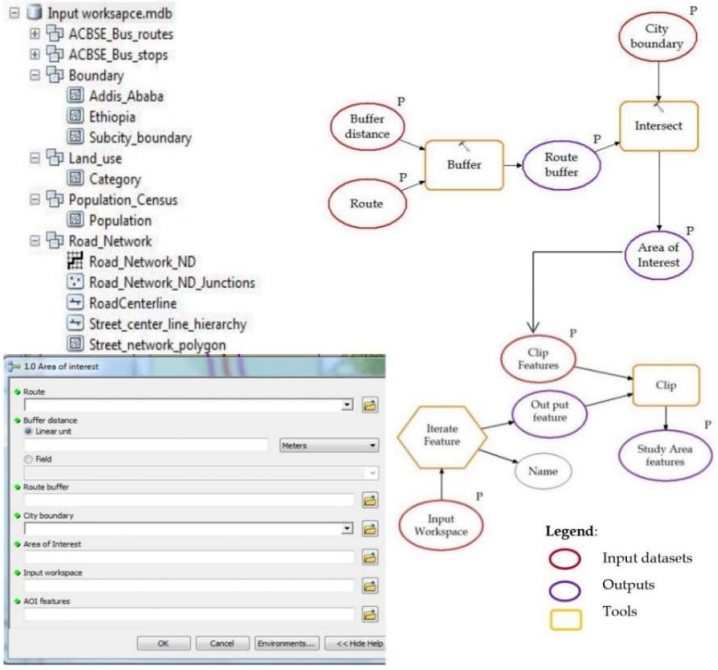


Figure 7 Area of Interest Model

3. Area of Interest

To accurately define the geographic boundaries of the study area and extract associated features a route line buffer is created by extending a zone around the route of interest 800m radially. While doing so it has been learnt that some zones are not be inside the city, as a result "Route buffer" is intersected with city boundary polygon using "Intersect" tool. Ultimately, to extract the datasets in buffer zones (i.e., "Area of Interest") all datasets were clipped iteratively through "Iterate feature" tool is integrated with "Clip" and store them in geo-database as shown in Figure 7. As shown in the figure, when the model is executed, a wizard shows up asking the necessary model parameters which are colored in red and purple colors to successfully run the model.

4. Service Area

One of the most well-known approaches for assessing service area is using buffer distance from facilities which is like buffering a point (i.e., circular buffer). Since using fixed route transit typically involves walking for access to and egress from bus stops into a person's daily routine, it plays a pivotal role in increasing physical activity and reduce overweight, blood pressure, diabetes and obesity which are the growing health concerns in Addis Ababa and the nation. Thereby proximity operation in GIS ArcGIS network analyst tools that consider actual street network and geographic obstacles is used to capture representative real catchment area covered in 10-minute walk from facilities considering CDC recommendation for a moderate physical activity which roughly

matches 500 meters at 0.9m/s. To do so the road network is processed to create a network dataset that models the street network form source features, which include lines and points. Then, ArcGIS Network analyst extensions are used to evaluate accessibility with concentric area with specified impendence (i.e., walking distance) as follows:

a) Prepare Feature Dataset and Sources

As discussed earlier all datasets are stored in the geo-database and the network datasets created are based on the said geo-database, hence all feature classes (i.e., road center line) are arranged to in one feature dataset (i.e., Road Network).

b) Create the Network Dataset

The dataset "Road network" that holds road centerline features is used to create network dataset with distance as the units of impedance value. Since most streets permit travel in either direction no changes have been made. Finally, network elements are created, connections are set up, and attributes are modified that result in a network dataset are built which stores the relationship and connectivity between elements (i.e., edges and junctions). Then data extracted in the prior analysis are consumed for this analysis, specifically "Bus stops" and "Network Dataset. Once data are found the said data are dragged into a new "Service area analysis" model from the "Input Workspace" geo-database.

c) Adding Geo-Processing Tools to Model

Prior to creating the model, the geo-processing tools necessary for the analysis are identified as "Make service area layer", "Add locations", "Solve" and "Buffer". Thereby the inputs and outputs of the model are defined as model parameters to make them show up when the model is executed and define their associated datasets from the folder connections established.

d) Add Network Analysis Objects and Create the Workflow

First the analysis layer is created with "Make service area layer", and then network objects are added to it using the Add Locations tool. Next the resulting outputs "Network Analyst Layer" are used to solve the service area problem at the specified impedance. When all these tools are connected, they form a workflow as shown in Figure 8 and the models are saved so that they can be re-used and updated. Finally, model parameters were defined.

e) Solve

To solve the analysis using the Solve tool, break values are set for multiple polygons breaks to create concentric service areas to find 300, 500, and 700-meter service areas for the same facility in the shortest street path for a perfect simulation of walking distance in the street network. For the case of this paper, a service area for a point on a network includes all the streets that can be reached within 500 meters is considered for further details.

5. Population in the Service Area

The projected population is provided at Kebele level as provided by the Ethiopian Central Statistical Agency in 2007 growth rate of 3.2% and thematically mapped in the route of interest with buffer radius of 800m. Further to get effective insight to accessible population that are

considered to be "Near" or "Served" by the existing bus stops service area polygons representing the area accessible within 500-meters from bus stations on a network were extracted using "feature to polygon" then spatial intersection of the service area and census data polygons is conducted using "Intersect" tool to answer "How many people live within 10 minutes of proximity from bus stops? "To do so "area "and "population" fields are added to dataset attributes to compute geometry of the polygons by "calculate geometry" tool. finally, population figures are derived from multiplying the service area and the population density per square kilometers since the data are joined spatially for each service areas using Field Calculator, the results of the data in the attribute table are further exported to excel using "table to excel" tool for summarizing the total population served in the route of interest.

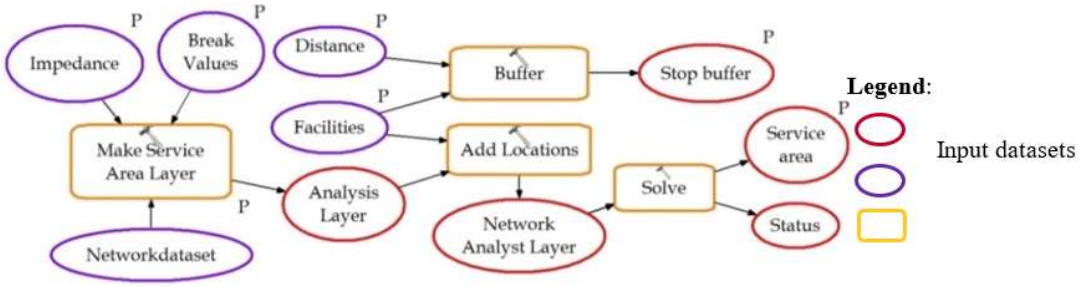


Figure 8 Service Area Model Workflow

6. Space-Time Accessibility Evaluation

After alternatives have been screened for their service area on the basis of equity relative merits of pursuing alternatives are evaluated to evaluate anticipated changes from proposed scenario; the appraisal process involves the accessibility analysis to provide a reliable picture of the benefits that could be associated with in the absence of the change and proposed course of action by computing the accessible population in each option are assembled for analysis to determine viability of option.