Improving Transit Access with Stop Spacing

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ABSTRACT

Transit operators consider stop spacing in addressing issues with bus reliability and travel time. But methodological processes for determining the frequency and location of stops vary widely. This paper presents the rationale and establishes a methodological process for identifying stop locations as a function of: distance to adjacent stops; population; and employment within catchment area; proximity to activity centers and transfer points; with public input to confirm preferences for identified stop locations.

The paper used transit route system data and census demographic data on two case study California counties of San Francisco and San Luis Obispo in GIS to determine concentrations of people and jobs by census block. To determine the catchment areas of existing or potential stop locations, buffers were created for potential stops based on published findings on distances people are willing to or typically do walk under various environmental conditions. A systematic location selection process was developed, applied and evaluated in terms of reductions in dwell time, increases in average travel speed, reduction in fuel consumption and associated estimates of cost savings.

This paper provides additional confirmation on the potential benefits of properly defined stop spacing. It offers a straight forward process based on readily available information to use in enhancing operations or in planning for future expansion.

The procedure presented in this paper for stop spacing therefore proposes a policy change from reliance on ridership estimation to direct application of demographic and spatial factors that are most important in safeguarding accessibility while enhancing performance. In a rough order of priority, the factors are: locations of the highest concentrations of population and employment; transfer points; major service centres; and steep grade segments. Then a combination of adopted stop spacing and acceptable walking distance is used to fill in, eliminate or relocate other stops.

Key Words

Transit, stop spacing, GIS, catchment area, buffer, activity concentration, distance separation, planning

1.0 INTRODUCTION

1.1 Objective

The objective of this **paper** is to **present** a methodological procedure that could be easily applied by transit operators and planners in designating stops for new or existing bus routes. The purpose of such a procedure is to help improve accessibility to transit (via stops) and make it more convenient for users. In so doing the procedure can help improve the performance of transit operations and reduce costs for operators.

1.2 Problem Statement

Transit operators throughout the world consider stop spacing in addressing such issues as increasing bus reliability and reducing travel times along routes. One factor that affects route travel time is dwell time at stops to allow passengers to get on and off. Another factor is the frequency of bus stops. If a bus stops frequently, there will be many dwell times and increased instances of acceleration and deceleration leading to increased fuel consumption. Concentrating passengers at few stops speeds up boarding per passenger over the course of the route and passenger loads become more predictable (Curitiba, 2003). Greater predictability can lead to greater accuracy in scheduling and ideally, greater reliability of the service. Reliability and schedule adherence are both factors that make the system easy for transit riders to use. Any savings achieved due to reduction in acceleration or deceleration, travel time and maintenance can be reinvested in the system in many forms. Savings can be spent on enhancing bus stop amenities at the stop locations, which can provide better customer information as well as better stop design to allow for faster, easier, and safer boarding. Savings due to decreased travel time can be translated into increased frequency along the route. Adequate bus frequency makes the service reliable and attractive to users. Any buses which may not be needed due to decreased travel times can be used for back-up to allow the agency to respond quickly when a bus breaks down during service. These widely-held notions indicate that there are potential benefits from optimal stop spacing.

Stop spacing goes far beyond a specification for only distance separation for stops. TCRP Report 19 lists several other criteria that may be considered in the decision on how to place stops, but there is no established methodological process for determining the frequency and location of stops. US cities adopt standards based on those adopted elsewhere and perceived suitability for their own conditions. This is done by either a committee or a team and findings are presented as informational documents. This paper proposes a methodological process for identifying stop locations as a function of factors such as distance to adjacent stops as well as catchment area's population and employment (which are indicators of potential ridership), proximity to activity centers and transfer points with public input to determine or confirm preferences for certain key locations.

1.3 Development of the Process

1.3.1 Review of Literature

The study involved a comprehensive review of published literature on stop spacing. The review also searched for distances people are willing to or typically do walk under various conditions of weather, topography and characteristics of the built environment. The objective of the review was to establish the state of the art in stop spacing. The review included information on transit systems in the US and abroad, especially Europe.

1.3.2 Collection of Data on Case Study Locations

The study collected transit route system data from transit operators in two case study locations. Transit system information and data were procured from the San Francisco Municipal Transportation Agency (SFMTA), San Luis Obispo Transit and the Regional Transit Authority (RTA) of San Luis Obispo County.

Data collected includes: (a) transit route network to identify general alignments of major intra-area and cross-area routes as well as key transfer points; (b) route profile data to identify high ridership points; (c) field inventory of stop locations to identify availability of amenities such as shelters, seats, rider information, etc.; and (d) major activity locations, that is, key origins and destinations such as major markets, employment centers, recreational spots and so on. All case study information was stored in a Geographic Information System (GIS). Other important information to help the analysis included point and shape files for case study locations on transit routes, road systems, topography and major activity centers.

1.3.3 Determination of Typical Catchment Areas for Transit Service

The latest available census data on the case study locations were retrieved and linked to the GIS. The Longitudinal Employment and Household Dynamics (LEHD) data provided information on populations of residents and employees by census block. The data were used to determine concentrations of people and jobs by census block. Then buffers of walking distances were created to determine the catchment areas of existing or potential stop locations, which encompass the pool of potential users of public transit.

1.3.4 Development Location Selection Process

A systematic process was developed for selecting stop locations. The process encapsulates the following considerations: proximity to activity centers; connectivity with cross-routes; transferability to other modes or routes; acceptability of a threshold population within a catchment area to reach the location.

1.3.5 Evaluation of Associated Savings

The location selection process was applied to the sample transit routes in the case study locations to determine improvements in the selections of stop locations. The operations under improved stop locations were evaluated in terms of reductions in dwell time, increases in average travel speed, reduction in fuel consumption and associated estimates of cost savings.

1.3.6 Synthesis for a Methodological Guide

Findings from the literature and case study applications were used to establish a systematic procedure for selecting stop locations. Methods and processes developed and applied in the study were laid out systematically as a series of guided steps for the application of the procedure in locating bus stops. Analytic processes were captured into application templates to accompany the text on procedural steps.

2.0 REVIEW OF SELECTED LITERATURE

2.1 Stop Spacing Research

There is a wealth of research on stop spacing covering theoretical concepts, optimization, simulation and empirical studies. Vuchic and Newell (1968) studied stop spacing analytically as a trade-off between access to transit and in-vehicle travel time. Close spacing of stops would reduce access time to transit, but would lead to increased, in-vehicle travel time since the vehicle has to make many more stops. The authors showed that stops should be spaced more closely as demand increases, meaning, as density of the built environment increases, but stops should be further apart as the number of passengers on board increases. The optimal spacing would therefore be the point where marginal change in users' access time equaled the marginal change in their in-vehicle time. The results supported the notion that stops for larger capacity vehicles that are carrying high loads of passengers, such as trains, should be more widely spaced than those for smaller vehicles.

Other authors broadened the scope of stop spacing to include associated costs. Wirasinghe and Ghoneim (1981) defined optimal spacing in terms of minimizing the costs associated with passenger access and egress, in-vehicle time, transit vehicle operation, the building of stops and the maintenance of stops. These considerations resulted in greater distances between stops than considerations based on the minimization of passenger travel time.

Van Nes and Bovy (2000) derived optimal stop spacing distances for a large city and a small city in the Netherlands based on passenger travel times (access, wait, and in-vehicle) plus costs and revenues to the transit operators. The authors applied simulation to derive optimal stop spacing distances for scenarios that included minimization of passenger travel time and minimization of costs to both passengers and operators. They derived the optimal stop spacing of approximately 1970 feet (600 meters) for the small city and approximately 2625 feet (800 meters) for the large city.

Furth and Rahbee (2000) used a combination of historic ridership data and geographic information systems (GIS) data on a heavily patronized route within the Massachusetts Bay Transportation Authority's (MBTA) transit system in a dynamic programming model to determine the optimal number and location of bus stops for the route. The authors allocated the number of boardings and alightings at various stops to parcels in the corridor to represent the spatial distribution of demand in the corridor. With assumed values of time for walking and riding the bus, operating costs and other operational factors, the authors applied dynamic programming to determine the number and location of stops that minimized time costs for riders and operating costs for MBTA. The findings resulted in a reduction of the number of stops by approximately half from 37 to 19 including the relocation of several of the stops. The study discovered the need to double stop spacing from about 650 feet (200 meters) to about 1300 feet (400 meters).

This paper has similarities with the MBTA study. It uses GIS data by census block rather than parcels but replaces historical ridership data with population and employment data to represent the spatial distribution of potential demand. This distribution is used to determine both efficiency in the alignment of routes and the preferred locations of stops. Thus it can serve as a tool in planning for existing settlements as well as future settlements when ridership data is not available. It is also similar to other studies that recognize the importance of accessibility to transit and the implications of cost for both riders and operators. It differs by not using mathematical programming, but is similar to simulation in the approach of using multiple criteria in a step-by-step approach to determining stop locations.

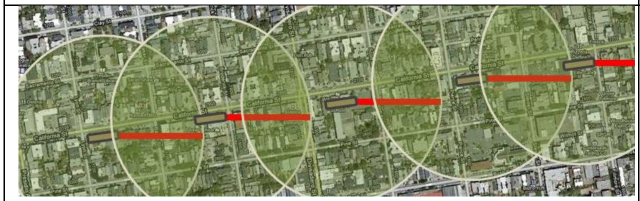
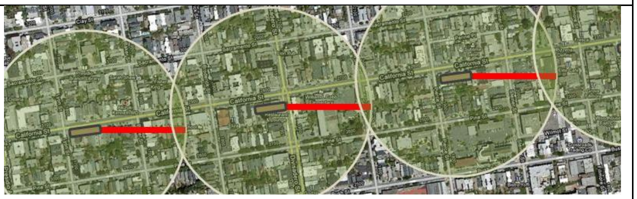
2.2 Impacts of Stop Spacing

It is evident from the literature that previous studies of stop spacing in terms of mathematical programming, optimization and simulation of operations have yielded much valuable insight into the benefits of optimal stop spacing. The study of the MBTA route by Furth and Rahbee (2000), for instance, revealed such pertinent findings from a doubling in stop spacing as: (a) a slight increase of 0.60 minutes in the average walking time for passengers but with a more than commensurate reduction of 1.8 minutes in the average in-vehicle travel time; (b) decline in average vehicle running time by 4.3 minutes; and (c) as a result, an estimated amount of $132 per hour in the combined savings to passengers and the MBTA. Saka (2001) related the improvements in operating speed from reduced stop spacing into reduction in fleet size and savings in capital costs.

El-Geneidy et al (2005) provided further confirmation with the study of bus reliability and travel time in the TriMet system of Portland, Oregon. To test the hypothesis that stop consolidation for fewer stops would concentrate passengers, reduce travel times and increase reliability, the authors divided route segments into two groups for the study: the “treated” segments had stop consolidation, and the “control” segments remained unchanged. The report shows that overall, the theory of concentrating passengers did decrease the overall running time, and did not reduce the number of passengers. Running times on the “treated” segments declined by between two and nine percent. The report also noted that running times could have been further reduced from what results indicated if schedules, which were adjusted to accommodate the stop consolidation, had been adjusted sufficiently. The report estimated that the elimination of each stop reduced running time by 42.2 seconds. The study did not find, however, that stop consolidation increased reliability, though this could be due to inadequate adjustments to schedules. However, previous studies have shown that boarding or dwell time could have an effect on the reliability of service (Turnquist, 1981). Kittelson & Associates (2006) identified such factors as the number of stops made to serve passengers and the number of left turns on public streets as significant variables that affect route travel time.

Figure 1 captures a summary of the trade-offs in placing stops close together or far apart (TCRP Report 19, 1996). The diagrams associated with the summary show that increasing spacing within reason could still maintain attractive walking distances to transit stops. This concept is relied upon heavily in the procedures presented in this paper.

Figure 1: Illustrative Trade-offs in Stop Spacing

Condition: *Bus stops approximately 800 ft. (244 meters) apart with 1/8 mile (1/5 km) access zones*	**Condition:** *Bus stops approximately 1200 ft. (366 meters) apart with 1/8 mile (1/5 km) access zones*
	
Close stops (every block or 1/8 to 1/4 mile) Short walking distances More frequent stops Slower bus speeds Longer bus trips	**Stops farther apart** Longer walking distances More infrequent stops Higher bus speeds Shorter bus trips

Sources: Text from TRCP Report 19 (1996)

2.3 Operator Benefits of Optimal Stop Spacing

The literature reveals certain benefits to transit operators with optimized stop spacing. Generally, the Federal Highway Administration (2009) recognizes that aggressive driving increases the fuel consumption of a vehicle. Aggressive driving is defined as accelerating and decelerating repeatedly. Though bus drivers are not necessarily aggressive, they must accelerate and decelerate for each bus stop. Vuchic (2007) states that “acceleration consumes most of the energy used in travel” and illustrates with a graph the increase in fuel consumption as stop spacing decreases. There is also data showing that vehicles get their best gas mileage at mid-range speeds, as opposed to driving very slowly or very fast (US DOE, 2009). Research also shows that for cars and trucks, fuel consumption, oil consumption, and vehicle depreciation are based on the constant velocity of the vehicle (TTI, 1990). Consumption of fuel, oil, and tires are all reduced as speed increases, and reductions are especially significant for each unit increase in mph at very low speeds. For trucks on flat terrain, an increase from 10 mph to 15 mph reduces fuel consumption by roughly 50 gallons per 1,000 miles. The same increase in speed reduces oil consumption by 10 quarts per 1,000 miles.

2.4 Stop Spacing Standards

A few transit agencies in the US developed stop spacing standards in recent decades: AC Transit (1989); TriMet (1989); Municipality of Metropolitan Seattle (1991); Chicago Transit Authority (2001); SFMTA (2009a). These efforts are in part attempts to replicate the successes that European cities have had in capturing high transit mode shares. The standards act as guidelines for agencies to determine where stops are needed or where consolidation is needed. Table 1 illustrates the wide variability in stop spacing among selected US cities. The table also reveals the varied standards applied within the network of each operator.

TCRP Report 19 (TTI, 1996) summarizes typical stop spacing based on the type of environment or density of an area. Findings indicate that there is a wide variation in stop spacing standards among US cities with shorter spacing in more densely built areas than lower density areas. The summary reveals that typical spacing could be two times as long in suburban and rural communities as in dense urban communities. This explains why this study looked at case locations in different types of urbanized areas.

Table 1: Stop Spacing Guides of Selected US and non-US Operators

Location (Operator)	**Conditions**	**Stop Spacing in Feet**		**Stop Spacing in Meters**		**Stops per Mile**		**Stops per Kilometer**	
		min	*max*	*min*	*max*	*min*	*max*	*min*	*max*
European Average[1]		1,320	1,750	400	530	3	4	2	3
London, UK[2]		1,310		400			4		3
Curitiba, Brazil[3]		1,640		500			3		2
San Francisco (SFMTA Proposed)	Grade below 10%	900	1,400	270	430	4	6	2	4
	Grade above 10%	500		150			11		7
Portland (TriMet)	High Density	780		240			7		4
	Low/Mid Density	1,000		300			5		3
Seattle (King County Transit)	Local	880	1,320	270	400	4	6	3	4
	Other	500	660	150	200	8	11	5	7
San Bernardino (Omnitrans)	CBD	1,000		300			5		3
	High to Medium Density	750	900	230	270	6	7	4	4
	Medium to Low Density	900	1,300	270	400	4	6	3	4
Chicago (Chicago Transit Authority [CTA])	Local	660	1,320	200	400	4	8	3	5
	Express	2,640	5,280	800	1,610	1	2	1	1
Alameda County (AC Transit)	Local	800	1,300	240	400	4	7	3	4
	Rapid	1,700	5,000	520	1,520	1	3	1	2

Sources: [1]Furth and Rahbee, 2000; [2]TFL, 2006; [3]Curitiba, 2003; AC Transit (1989); CTA (2001); SFMTA (2009a); TriMet (1989); Seattle (1991).

The literature also reveals slightly wider spacing abroad than in the US. According to El-Geneidy et al, (2005), “Furth and Rahbee (2000) observe that stops in northern European cities are spaced much further apart than in comparable US settings, yet the European transit systems are still able to capture a greater share of the urban travel market. Reilly (1997) also found that the common European practice was to space stops at 3 to 4 per mile compared to the U.S. practice of 7 to 10 per mile” *(as in Table 1)*.

The 2006 Transport for London (TFL) Bus Stop Accessibility Guideline (TFL, 2006) recommends 400m (~1310 feet) as a good approximate stop spacing distance. The Curitiba bus system (Curitiba, 2003) uses a longer stop spacing distance of 500m (~1640 feet). Curitiba cites the stop distance as the limiting factor for the speed of buses as major bus routes operate in exclusive rights-of-way.

The difference between these guidelines and those by US agencies is clear. Although the non-US cities do not recommend a minimum or maximum, the average stop spacing is in most cases higher than the maximum recommended stop spacing in many US cities. European transit systems have higher market shares, and many elderly or disabled persons are able to use the routes. One reason could be the relatively high cost of gas in most European countries compared to the US, however, different transit systems have developed as well. The reason behind the development of different systems in Europe and the US is political, according to Furth and Rahbee (2000). Services in the US have fewer guidelines for stop spacing, and in some cases, any stop requests were fulfilled without further consideration. There are political benefits to placing a bus stop in a neighborhood because it is a direct, local, and visible action. However, the overall impact of placing stops wherever they are requested is a decrease of bus speeds across the course of the route (Furth and Rahbee, 2000). This is a large subject of debate but means nevertheless that we cannot assume that American stop spacing standard (or lack thereof) is best able to serve customers.

2.5 Acceptable Walking Distances

Many documents (e.g. TriMet, 2002) specify that ¼ mile (0.4 km) is the acceptable distance that a person should have to walk to a bus stop. During off peak or night services, ½ mile (0.8 km) to 1 mile (1.6 km) (Chicago Transit Authority [CTA], 2001) are considered optimal distances. Information supporting pedestrian access (Pedestrian and Bicycle Information Center, 2009) also states that ¼ to ½ mile (0.4 to 0.8 km) is the distance people will walk to access transit.

2.6 Site-Specific Issues

This study focuses on the general demarcation of stop locations and the distance separation between them. Other studies have dealt with site-specific considerations with treatment options under certain scenarios. Issues to be considered relate to operations, pedestrians and others. For instance, TCRP Report 19 (1996) identifies several operations-focused factors for consideration in site-specific treatments that relate to the needs of passengers who would use the transit route, characteristics of the streets which the transit route traverses and the existence or potential for bus priority treatment.

Similarly, the Transport for London Report (2006) emphasizes accessibility and appropriateness of the site for pedestrians. The report identified such pedestrian-focused criteria for site-specific considerations as:

a. Clear visibility between driver and prospective passengers
b. Adequate footway (sidewalk or path) width
c. Freedom from obstructions
d. Proximity to pedestrian crossings
e. Availability of space for a bus shelter

f. Minimum walking distance to transfers
g. Proximity to intersection without affecting pedestrian safety at the intersection

TCRP Report 19 (1996) further discusses issues associated with locating transit stops close to or farther from intersections and summarizes the advantages and disadvantages associated with near-side, far-side and mid-block stop locations. The terms far-side and near-side refer to the placement of stop locations at intersections. As a bus approaches an intersection, a stop located before passing through the intersection is a near-side stop; a stop located immediately after the bus passes through the intersection is a far-side stop. Any stop in between these areas is considered a mid-block stop.

2.7 The Use of GIS in Transit Planning

The literature acknowledges increasing use of geographic information systems (GIS) in transit planning. Horner and Murray (2004) conducted an extensive review of research on GIS use in transit planning. The study focused on the use of GIS to delineate geographical areas of demand for public transit. The authors noted the emphasis of research on modeling transit use with GIS at the expense of paying attention to spatial considerations that underlay the GIS-based analysis. The study investigated issues of spatial scale, that is, choice of individual stops vs. entire routes or Euclidean distances vs. network distances in estimating demand. The study concluded that spatial representation critically impacted the results of the analysis.

Gutierrez and Garcia-Palomares (2008) acknowledged the importance of proximity of population and employment to stops and stations on potential usage of public transit. The study focused on the choice between Euclidean vs. network distances in the creation of coverage areas, represented as buffers, with the aid of GIS. The study concluded that the method of using network-based distance provided better estimates of transit ridership that the method of Euclidean distance.

The availability of census population and employment data at the block level facilitates spatial analysis with GIS at a detailed geographic scale rather than the macro level of the traditional travel analysis zones. Previous studies confirmed that estimates of public transit coverage based on census blocks are not only the most disaggregate, but also most closely represented the population served (Horner and Murray, 2004; Peng and Ducker, 1995). That is the method presented in this paper. A feature that differentiates this study from others is that the procedure includes consideration for multiple criteria, such as access to services, transfer points and grades instead of a strict focus on distance and network representation or strict employment and population coverage. Finally, consistent with other research findings, the procedure of this paper used network distances to demarcate coverage areas. Unlike many other studies directed at projecting transit ridership or site treatment for stop locations this study focused on the spacing of stops under consideration of multiple factors.

2.8 Discussion of Literature

Neither individual research results nor adopted guidelines of various operators seem to provide consistent indications on what should be the standards for spacing stops. The fact is there are many factors, which relate to acceptability of time to access public transit, the level of tolerance for total travel time, the cost of providing service, the density of development and the level of patronage for transit service. Certain generalizations are in order as follows:

a. There is general recognition that people are willing to walk ¼-mile (0.4 km) to access human activities, but some people accept ½-mile (0.8 km) and under special circumstances, people would even walk a mile (1.6 km). Walking distance is a primary determinant of the radius that defines the catchment area of a stop. If two adjacent stops have ¼-mile (0.4 km) catchment areas, then the separation between them is two adjacent radii or ½-mile (0.8 km). This distance defines the upper limit of separation in adopted guidelines of operators for suburban environments. A half-mile (0.8 km) separation is thus used in this study as the target distance for small urban and suburban areas.
b. There is the general tendency for most study results to prescribe shorter distances for dense urban areas than for more sparsely developed areas. This is reflected in the adopted guidelines of operators although the actual distance of separation is widely variable. Simulation results and guidelines from abroad all seem to point to approximately four stops per mile or ¼-mile separation (0.4 km)) which would result in a non-overlapped catchment area radius of 1/8-mile (0.2 km) per station. A quarter-mile (0.4 km) separation is thus used in this study as the target distance for large urbanized areas.
c. There are two variations from these two target distances. One relates to separation for "express" or "rapid" service, which tends to be two times the prevailing separation or ½-mile to a mile (0.8 to 1.6 km). The other relates to steep segments of 10 percent grade or more, which tend to prescribe half the prevailing separation.

3.0 STUDY FINDINGS AND DISCUSSION

3.1 Key Findings

3.1.1 Sample Result of Procedure

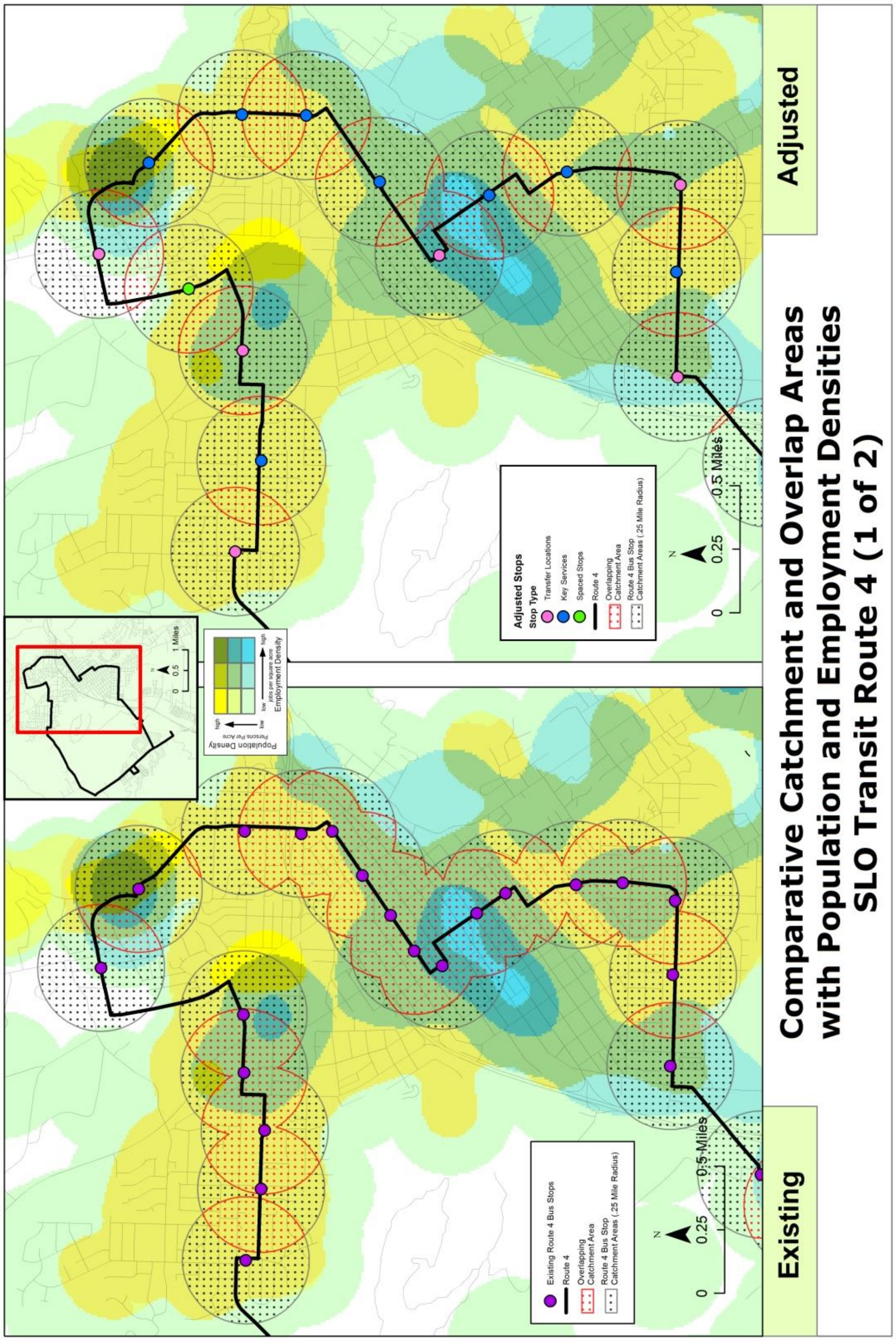
Figure 2 provides a sample application of the procedure to route alignments and stop locations with a combined mapping of population and employment concentrations. It also compares alignments and locations with and without application of the procedure.

3.1.2 Estimated Savings

The application of the proposed procedure to the case study routes produced results that are consistent with findings in the literature. Key results of its application to the specific case study routes may be outlined as follows:

a. Reduction in the number of stops by 10 percent to 44 percent;
b. Reduction in buffer overlaps by 9 percentage points to 44 percentage points;
c. Less than commensurate reduction in coverage area of 0 percent to 13 percent, which would mostly affect those on the fringes of the catchment areas of stops;
d. Potential reductions in route travel time for all patrons ranging from 1 percent to 12 percent for the low estimate and from 3 percent to 32 percent for the high estimate.

Figure 2: Comparative Buffer Overlaps vs. Activity Centers along Route 4



3.2 Discussion

It is an obvious notion that as more people live or engage in other human activities close to transit stops, the more accessible the service would be to them and the higher the potential of using it. Many transit operators established several stops to realize this notion. However, for a given traffic and roadway condition, the more frequent stops are along a route the slower the route travel time due to deceleration, stopping and acceleration. So also the farther stops are from each other, the longer the average distances for access and egress. Early research revealed that the optimal spacing therefore is one that minimizes total travel time, which includes access and in-vehicle times.

Further research has shown that there are operating cost increases associated with close spacing and operating cost savings associated with wide spacing. The optimal spacing therefore is one that minimizes total costs, which include travel time costs to transit users and operating costs to transit providers. Such an achievement would both improve operational efficiency and maintain good accessibility. Accessibility can be dealt with by guaranteeing that population concentrations are within acceptable walking distances to transit, which the literature places at a quarter to a half mile (0.4 to 0.8 km). Other provisions can also improve accessibility by accommodating those who would access the service by other modes. Some examples are bicycle parking for bicyclists, convenience of transfer for users of other transit service, and parking or drop-off locations for automobiles. If too large and not in a structure, automobile parking can occupy so much space as to extend the access distance for walkers and bicyclists. The preferred policy would be to concentrate activities and locate stops in such a way as to prioritize walk access.

Research revealed that stop spacing is generally shorter in the US than other countries abroad, but transit use is higher in those places. In general, European cities recommend 3 to 4 stops per mile (2 to 3 per km), or approximately 1300 feet (400 m) of separation. American guidelines recommend stops between approximately 500 to 1300 feet (150 to 400 m) of separation. While increasing stop spacing distances could increase walking distances for some users, in places with high transit stop density, most access distances will remain within the acceptability threshold of a five- to ten-minute walk. This study added confirmation to this observation. Studies have also shown that fewer stops will concentrate passengers at the remaining stops along the route, which can increase predictability, allow for a more accurate schedule, and result in a more reliable service. Concentrating passengers can also reduce the dwell time per passenger per stop, which leads to an overall reduction in route travel time. Reducing travel time reduces operating expenses which in turn could enable operators to provide more stop amenities. Reduced operating expenses may also translate into more frequent service. Ultimately, a more reliable service means passengers will spend less time waiting at bus stops.

This study has similarities with previous studies. It uses GIS data by census block but with population and employment data rather than ridership to represent the spatial distribution of potential demand. This distribution is used to determine both the efficiency in the alignment of routes and the preferred locations of stops. Thus it can serve as a tool in planning for existing settlements as well as future settlements when ridership data is not available. It is also similar to other studies that recognize the importance of accessibility to transit and the implications of cost for both riders and operators. It differs by not using mathematical programming, but is similar to simulation in the approach of using multiple criteria in a step-by-step approach to determining stop locations.

The procedure for stop spacing used in this study considers the factors most important to safeguard accessibility while enhancing performance. In a rough order of priority, the factors are: locations of the highest concentrations of population and employment; transfer points; major service centers; and steep grade segments. Then a combination of adopted stop spacing and acceptable walking distance is used to fill in, eliminate or relocate other stops.

The appeal of this procedure lies in its simplicity. Input to the process is readily available. Block level data is obtainable by fine geographical area for population and employment from the US census. Instead of reliance on the decennial census, most recent data is available because of the American Community Survey and the data is easy to obtain from the Census LEHD online mapping application. Although it does not involve specific linear programming formulation, the procedure still encapsulates factors of user convenience and time costs as well as operator costs. These were termed in the literature operating and societal costs.

4.0 RECOMMENDED PROCEDURE

This paper recommends adoption of a methodology for routine application by transit planners and operators. The methodology is presented in four theme areas: spatial analysis framework; stop spacing distances; the step-by-step stop spacing procedure; and public input.

4.1 Spatial Analysis

The geographical detail of spatial analysis is important in stop spacing. The literature postulates that estimates of public transit coverage based on census blocks have proven to be the most disaggregate and the most representative of the population served. The availability of census population and employment data at the block level facilitates spatial analysis with GIS at a detailed geographic scale rather than the macro level of the traditional travel analysis zones. The data also provide alternatives to estimates of ridership. Planners are well-served to conduct analysis at the census block level for which data is readily available.

Where tools permit, network distances (rather than Euclidean distances) should be used to demarcate catchment or coverage areas of stops. The availability of robust GIS software facilitates this type of spatial analysis.

4.2 Stop Spacing Standards

There is general recognition that people are willing to walk ¼-mile (0.4 km) to access human activities. If two adjacent stops have ¼-mile (0.4 km) catchment areas, then the separation between them is two adjacent radii or ½-mile (0.8 km). This distance defines the upper limit of separation in adopted guidelines of operators for suburban environments. Use a half-mile (0.8 km) separation as the target distance in built-up portions of small urban and suburban or rural areas.

There is the general tendency for most study results to prescribe shorter distances for dense urban areas than for more sparsely developed areas. Simulation results and guidelines from abroad all seem to point to approximately four stops per mile (3 stops per km) or ¼-mile separation (0.4 km) which would result in a non-overlapped catchment area radius of 1/8-mile (0.3 km) per station. Use a quarter-mile (0.4 km) separation as the target distance for densely built portions of large urbanized areas.

Vary these two target distances under two circumstances: (a) for “express” or “rapid” service, use two times the prevailing separation or ½-mile (0.8 km) to a mile (1.6 km); (b) for steep segments of 10 percent grade or more use half the prevailing separation.

4.3 Stop Spacing Procedure

The adopted stop spacing procedure should include consideration for multiple factors, such as proximity to concentrations of human activities, ready access to services, potential for transfers, topography and density of urban development. The latter dictates the target separation distance. The process in a nutshell is outlined as follows:

1. Identify population concentrations by census block using Census data for the latest available year. To do this, create a Raster map (or thematic map) of concentrations of people in a GIS software.
2. Identify major employment concentrations by census block using the latest available employment and shape file data from Census LEHD website. To do this, create a Raster map (or thematic map) of concentrations of jobs in a GIS software.
3. For an existing route, add the existing transit route configuration and stops to the map.
4. For a new route, use the thematic maps to determine the general alignment for the route to connect high intensity centers.
5. Identify cross route locations for transfers and add them to the map
6. For an existing route, add a database of amenities (shelter, benches, route maps, etc.) present at individual stop locations and add them to the map. These can help in determining stops to retain where choices need to be made between adjacent locations.
7. Identify primary stop locations from the previous steps.
8. Create buffers of 0.25-mile (0.4 km) radius around the primary stops for most types of built environments and 0.125-mile (0.2 km) radius for the dense urban environments.
9. For an existing route, use the buffers to determine where there is too much overlap so as to flag potential stops for elimination or re-positioning; in other areas, use the buffers to identify intermediate locations to achieve convenient, walkable access from nearby land uses.
10. For new routes, use the buffers to determine intermediate locations to achieve convenient, walkable access from nearby land uses.

4.4 Public Input

Once the stop placement is completed, public input is desirable. First it would serve as a forum to inform the riding public or potential riders about the rationale for selecting stop locations. It would also help in choosing from alternative locations that are close to each other and in confirming transfer and connection points identified from data. Public input can help in determining which stop removals could have significant adverse impacts on such disadvantaged groups as the transit-dependent, elderly, or disabled. It can also help to identify issues that may be associated with the placement of certain stops.

4.5 Site-Specific Treatments

Following the general demarcation of stop locations, site-specific adjustments and treatments may become necessary. These types of scenarios are dealt with in TCRP Report 19 (1996). They deal with issues related to the needs of passengers who would use the transit route, accessibility and appropriateness of the site for pedestrians, characteristics of the streets which the transit route traverses and placement near or far from intersections.

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References

AC Transit. (1989). Bus Stop Policy. Retrieved from http://www.actransit.org/pdf/board_policies/policies/board_policy_41.pdf?PHPSESSID=ea1551e056d7713ab34838ed2b92dc94.; last accessed 6/27/2011

American Community Survey (2008). Table C08301 Means of Transportation to Work.

Chicago Transit Authority. (2001). Chicago Transit Authority Service Standards. Chicago, IL.

Chicago Transit Authority (2003). Neighborhood Express Bus Routes. Retrieved from http://www.fta.dot.gov/assistance/technology/research_4324.html; last accessed 6/27/2011

Curitiba, Brazil: BRT Case Study. (2003). Retrieved from http://nexus.umn.edu/Courses/ce5212/Case3/Curitiba.pdf; last accessed 6/27/2011

El-Geneidy, A., Kimpel, T., and Stratham, J. (2005). Empirical Analysis of the Effects of Bus Stop Consolidation on Passenger Activity and Transit Operations. Retrieved from http://www.upa.pdx.edu/CUS/publications/projectreports.html.; last accessed 6/27/2011

Federal Highway Administration. (2009). 10 Simple Steps to Reducing Climate Change. Retrieved from http://www.fhwa.dot.gov/hep/climate/tensteps.htm.; last accessed 6/27/2011

Federal Transit Administration. (2006). Stops, Spacing, Locations and Design. Retrieved from http://www.fta.dot.gov/assistance/technology/research_4361.html.; last accessed 6/27/2011

Furth, P., & Rahbee, A. 2000. Optimal bus stop spacing through dynamic programming and geographic modeling. Transportation Research Record, 1731: 15-22.

Gutierrez, Javier, and Juan Carlos Garcia-Palomares, 2008, Distance-measure impacts on the calculation of transport service areas using GIS, Environment and Planning B: Planning and Design, vol. 35, pp. 480-503

Horner, Mark and Alan Murray, 2004, Spatial representation and scale impacts in transit service assessment, Environment and Planning B: Planning and Design, vol. 31, pp. 785-797

Kittelson and Associates. (2006). Transit Speed and Delay Study. Prepared for Florida Department of Transportation. Portland, OR.

Liu, R., and Sinha, S. (2007) Modeling Urban Bus Service and Passenger Reliability. Conference Proceedings from The Third International Symposium on Transportation Network Reliability. The Hague, Netherlands.

Massachusetts Executive Office of Transportation. (2008). Route 39 Enhancement Plan. Retrieve from http://www.eot.state.ma.us/downloads/;Route_39_Presentation.pdf.; last accessed 6/27/2011

Municipality of Metropolitan Seattle. (1991). Metro Transportation Facility Design Guidelines. Seattle, WA.

Municipality of Metropolitan Seattle (1991). Metro Transportation Planning Facility Design Guidelines. Seattle, WA.

Murray, A., & Wu, X. (2003). Accessibility tradeoffs in public transit planning. Journal of Geographical Systems, 5(1): 93-107.

Pedestrian and Bicycle Information Center. (2009). Improving Transit Stop/Station Access. Retrieved from http://www.walkinginfo.org/transit/access.cfm.; last accessed 6/27/2011

Peng, Z. Ducker K, 1995, Spatial data integration in route-level transit demand modeling, Journal of the Urban and Regional Information Systems Association, vol. 7, pp.26 – 37

Reilly, J. 1997. Transit service design and operation practices in western European countries. Transportation Research Record 1604: 3-8.

Saka, A. 2001. Model for determining optimum bus-stop spacing in urban areas. Journal of Transportation Engineering, 127(3): 195-199.

San Francisco Municipal Railway. (1979). Short Range Transit Plan (1979-1984). San Francisco, CA.

San Francisco Municipal Transportation Agency. (2009a). Presentation on Stop Spacing. San Francisco, CA.

San Francisco Municipal Transportation Agency. (2009b). Transit Effectiveness Project. Retrieved from http://www.sfmta.com/cms/mtep/tepover.htm; last accessed 6/27/2011

Texas Transportation Institute. (1990). Technical Memorandum for National Cooperative Highway Research Program Project 7-12. College Station, TX.

Texas Transportation Institute. (1996). Guidelines for the Location and Design of Bus Stops. TCRP Report 19, Transit Cooperative Research Program, Transportation Research Board, National Research Council.

Transport for London. (2006). Accessible Bus Stop Design Guidance. London, UK.

Tri-County Metropolitan Transportation District of Oregon. (2002). Bus Stop Guidelines 2002. Portland, OR.

Tri-County Metropolitan Transportation District of Oregon. (1989). TriMet Service Standards. Portland, OR.

Turnquist, M. (1981). Strategies for improving reliability of bus transit service. Transportation Research Record 818: 7-13.

United States Department of Energy (2009). Driving more efficiently. Retrieved from http://www.fueleconomy.gov/feg/driveHabits.shtml.; last accessed 6/27/2011

United States Department of Justice. (2005). A guide to Disability Rights Law. Retrieved from http://www.ada.gov/cguide.htm.; last accessed 6/27/2011

van Nes, R., and Bovy, P. 2000. Importance of objectives in urban transit-network design. Transportation Research Record 1735: 25-34.

Vuchic, V. (2007). Vehicle Motion and Performance. In Urban Transit: Systems and Technology. Hoboken, NJ.

Vuchic, V. and Newell, G. 1968. Rapid transit interstation spacing for minimum travel time. Transportation Science, 2(4): 303-339.

Washington Area Metropolitan Transit Authority. (2009). Metrobus Veirs Mill Line Study. Retrieved from http://www.metrobus-q2.com/index.htm; last accessed 6/27/2011

Wirasinghe, S., & Ghoneim, N. 1981. Spacing of bus stop for many to many travel demand. Transportation Science, 15(3): 210-221.