

Stop Spacing Analysis Using Geographic Information System Tools with Parcel and Street Network Data

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Geographic databases and computing tools present an opportunity for improved analysis of bus stop location or spacing changes. Changes in stop location affect walking, riding, and operating cost; of these, the impact on walking is the most important and complex. Traditional models and design rules for stop spacing do not model the impact on walking precisely, because they assume uniform demand density and unobstructed walking paths. This paper discusses an analysis procedure based on a parcel-level geographic database (supplied by a local government body such as the city tax assessor) and a street network. Walking paths and stop service area boundaries are based on shortest path and Voronoi diagram methods applied to the street network. Data on each parcel's land use and development intensity are used to distribute historic on-off counts and thus estimate the demand arising in each parcel. For alternative stop sets, then, the demand at each stop, walking distance, riding time, and operating cost impacts can be determined. Case studies on transit routes in Boston, Massachusetts, and Albany, New York, demonstrate the method's practicality. Results confirm the benefits of a recent stop rationalization effort in Boston and show how proposed stop elimination and relocation plans can be adjusted to yield a greater net benefit to society.

Stop spacing is an important part of transit service design as it affects passengers' walking time and the operating speed of a route, which affects both riding time and operating cost. Many people have observed that bus stops tend to be spaced much closer in the United States (typically 200 m, or $\frac{1}{3}$ mi) than in Europe (typically 320 m, or $\frac{1}{2}$ mi) (1) and believe that the U.S. dense stop spacing makes American transit service slow and unattractive. Many U.S. transit agencies are trying to increase operating speed by rationalizing stop spacing, both as part of bus rapid transit initiatives and for regular routes. To support such efforts, methods are needed to determine the impacts to both passengers and operations of changing stop spacing.

The chief difficulty in analyzing stop spacing is determining the impact on walking, which until now has been done with simplistic methods. Because passenger travel behavior and satisfaction is sensitive to walking time, more accurate methods are needed for

determining walking distance to and from stops. This presents two challenges.

First, transit agencies have little knowledge of their customers' ultimate origins and destinations (trip ends). Absent such information, common practice is to assume that trip ends are uniformly distributed in a stop's service area. However, in reality, varying land uses and development intensities in a stop's service area can lead to strong local concentrations in trip ends, which should influence stop location. Within a stop's service area, there may be single-family homes and apartment buildings, cemeteries, and hospitals; transit demand is certainly not the same from each. An analysis method that recognizes where demand is more likely to originate will more accurately estimate walking impacts and will rightly favor stop locations closer to heavy trip generators.

The second challenge, once trip end locations are determined, is to determine walking distances that reflect feasible walking paths in the access network. Stop spacing methods found in the literature as well as those used in practice estimate walking distance using simple models—either a sum x - and y -components perpendicular to and parallel to the transit route (following from the assumption of an infinitely dense rectilinear grid) or airline distance multiplied by a circuitry factor. These simple models are unrealistic, failing to account for the discontinuities, curves, and shortcuts often found in the access network. Equally important, an earlier study (2) showed how the discrete nature of the access network effectively concentrates demand at street junctions along the transit route, resulting in a demand distribution resembling a mix of point loads (at intersections) and distributed loads. These demand concentrations substantially influence optimal stop location.

The stop spacing analysis method proposed in this paper resolves these challenges by using two kinds of geographic databases. The first describes all of the land parcels in a route's service area. Such databases, available from many cities' tax assessor's office, give each parcel's land use type and contain measures of development intensity, such as gross floor area, that can serve as a basis for distributing demand. The second is the street network, widely available in digital form. Using these databases in a geographical information system (GIS), demand is distributed over the route's service area in a way that reasonably reflects each parcel's ability to produce and attract trips, and walking distance is determined along realistic paths within the access network.

Following a brief review of the literature and industry practice, this paper describes in more detail the parcel and street databases used in case study applications to a light rail line in Boston, Massachusetts, and a bus route in the Albany, New York, region. The proposed method is then described, and results are given from the case studies.

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LITERATURE AND PRACTICE REVIEW

Theoretical models based on continuum approaches, such as those discussed in Van Nes and Bovy (3) and Gan et al. (4), are effective tools for exploring the trade-off that stop spacing poses between passenger walking time, passenger riding time, and operating cost, which is proportional to cycle time. Walking time increases with stop spacing, while the other two impacts, which are both related to vehicle speed, decrease—resulting in an overall cost function that is convex (U-shaped) with a minimum occurring at a point of optimal trade-off. Optimality conditions are such that optimal stop spacing is not constant along a route; rather, it increases with through volume (which is often greatest in the middle of a route) and cruising speed (which is greatest where buses do not have to stop for traffic signals or stop signs) and decreases with passenger demand density (which tends to be greatest in downtown areas).

(On fixed guideway routes, the cost of building and operating stations becomes a major issue. It can lead to wide stop spacing, which can depress demand because passengers find the walking distance to the nearest stop to be excessive. The latter effect is also important in designing limited-stop bus rapid transit routes, but not local routes for which interstop spacing is generally constrained.)

As discussed in Furth and Rahbee (2), continuum models are impractical for application, and so industry practice, also reviewed in this reference, is to use simple design guidelines such as “8 stops per mile,” directly contradicting the result that optimal stop spacing should vary along a route. In stop rationalization studies, transit agencies and consultants use ad hoc design methods (e.g., eliminate low-demand stops, subject to a maximum stop spacing). However, there are no available methods for evaluating the impact of a proposed change in stop location, apart from local application of the continuum approach, estimating average walking distance parallel to the transit line as $s/4$ where s is the stop spacing, and assuming that walking distance perpendicular to the transit line is unaffected by stop spacing. The method proposed in this paper fills that void, evaluating the impacts of stop location changes based on the actual geography of the street network and urban development.

GIS-based methods [e.g., see Wirasinghe and Ghoneim (5)] have also been used to suggest stop locations. However, they rely strictly on population data and assume walking distance based on airline or rectilinear travel. This may be a reasonable approach for designing a new transit route for which demand is hard to predict; however, for an existing route, this approach ignores the vital demand information contained in on-off counts, fails to account for demand generators other than homes, and does not account for the discrete effects of the access network.

GIS DATA SETS AND TOOLS

The proposed method takes advantage of two geographical data sets. One is the street network, which was found to be readily available. In the Boston case study, this network needed some minor edits to reflect more accurately the walk access network (a few walking paths had to be added, and tiny links had to be added in some cases to connect the bus stops to the street network).

The second is the land parcel data set. In Boston, this data set is readily available for a nominal price from the city tax assessor's office; in the Albany area, it was supplied by the regional planning agency to the transit agency. The Boston data showed physical loca-

tion using a parcel polygon shape file; the Albany data had parcel point data in MapInfo. Both gave each parcel a land use code, though land use definitions and detail differ. The parcel data also provided a measure of development intensity or size for trip distribution. For Boston, the measures of size used were living area (for residential land uses) and gross floor area (for other land uses). For Albany, the measures used were household size (not available in the Boston data set) for residential properties and number of employees for nonresidential properties.

The commercially available GIS platform that was used includes several network algorithms that made the analysis easier. One finds the centroid of each parcel; in further analysis, parcels were treated as points located at their centroid. Another is the closest facility tool. Treating parcel centroids as demand points and bus stops as facilities, it finds the closest stop to each parcel centroid, along with the shortest path tree from each stop to its assigned parcels. The authors also programmed many of their own analysis tools using that platform's programming language, Avenue.

DETERMINING STOP SERVICE AREAS

Stop service areas are determined by the principle that users choose the stop that minimizes a weighted sum of their walk time and ride time. The service area of a stop is different for trips beginning versus ending there. For trips beginning at parcel k , the stop chosen is the one that minimizes, over all stops i ,

$$ucost_{walk} * d_{ki} / speed_{walk} + runtime_{i,j} \quad (1)$$

where

d_{ki} = walking distance from parcel k to stop i ,

$ucost_{walk}$ = cost of a minute of walking time relative to a minute of riding time (commonly given a value between 1 and 2.5),

$speed_{walk}$ = walking speed, and

$runtime_{i,j}$ = running time from stop i to the downstream terminal.

Using the downstream terminal in Equation 1 provides a correct basis for passenger stop selection regardless of a passenger's downstream destination. If that destination is stop d , the difference in riding time between alternative origin stops i and j is ($runtime_{i,d} - runtime_{j,d}$), which is the running time from i to j .

For trips ending at parcel k , the stop chosen is the one that minimizes, over all stops i ,

$$ucost_{walk} * d_{ik} / speed_{walk} + runtime_{i,j} \quad (2)$$

where $runtime_{i,j}$ is the running time from the upstream terminal to stop i . Because walking is a substitute for riding, stop shed lines are not equidistant between neighboring stops; rather, they shift upstream for boardings and downstream for alightings, as pointed out in previous theoretical analyses (2, 6). In general, a parcel has four different assignments to stops, one each for inbound boarding, inbound alighting, outbound boarding, and outbound alighting.

In the idealized geometry used in continuum models, shed lines are simply the perpendicular bisectors of the segments between adjacent stops, shifted slightly upstream or downstream as mentioned earlier (2). However, if the transit line curves or turns, if streets in the access network are curved, skewed, or discontinuous, or if

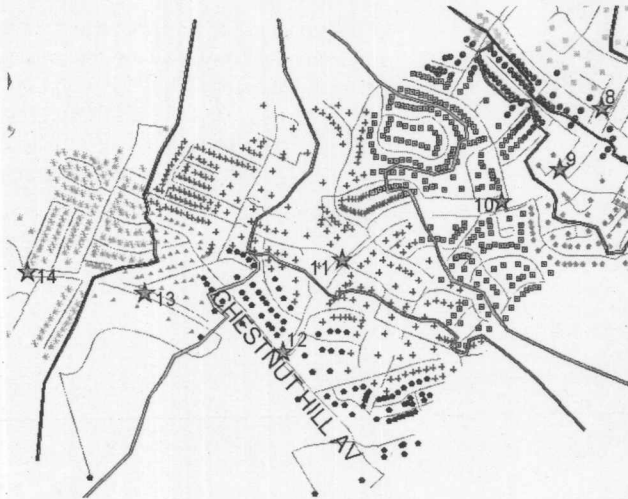


FIGURE 1 Outbound stop service area boundaries for part of Boston's B-Line. Manually drawn lines show stop service areas for boardings; parcel symbols indicate stop assignment for alightings.

a stop is midblock or at a T-intersection, service area boundaries can take on shapes that cannot be predicted except by network analysis.

An example from part of Boston's B-Line outbound (Figure 1) shows irregular service area boundaries that result from the particular features of the network. It illustrates how, contrary to what is predicted by an idealized model, a stop can have a boundary with

more than just its immediately neighboring stops; for example, for alightings, Stop 11 has a service area boundary with not only Stops 10 and 12 but also with Stops 13 and 14. One can also see large differences between the service areas for boardings versus alightings and how the boardings shed lines are shifted upstream (to the right) and alightings shed lines shifted downstream.

DIRECT PARCEL STOP ASSIGNMENT VERSUS TWO-STAGE ASSIGNMENT USING A NETWORK VORONOI DIAGRAM

In order to assign parcels to the stop with the shortest combined walking and riding time using the Closest Facility algorithm, a virtual access link from the street network to each transit stop was added whose cost is the riding time from that stop to the end of the line (for boarding trips) or from the start of the line to the stop (for alighting trips), weighted to reflect the difference in unit cost of walking and riding. An example output of this assignment is shown in Figure 2, showing both the parcel stop assignment and the shortest path tree used for walking paths.

An equivalent two-stage approach to calculating the parcel stop assignment was also tested. In Stage 1, the Voronoi diagram (a partition of the network into service areas based on the closest facility) is calculated on the street network, with dummy access links at each stop representing riding time to or from the end of the line as before. The authors programmed and used the Dijkstra network Voronoi algorithm (7), which finds the closest stop, with shortest path tree, to every junction in the road network. Every link whose nodes are not assigned to the same stop is a boundary link, which is then divided at a calculated indifference point. Every link that is not part of a shortest path

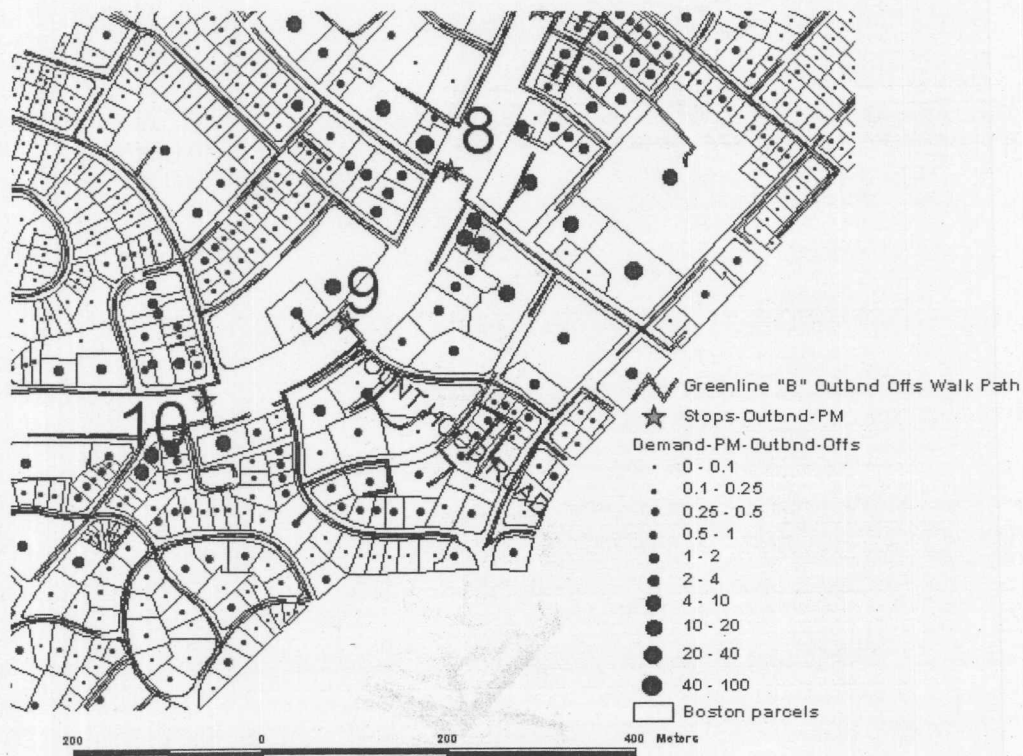


FIGURE 2 Walking paths and parcel stop assignment near Stop 11 (Mt. Hood Road).

tree but whose end nodes are assigned to the same stop is likewise split at an indifference point in order to complete the shortest path tree. A network Voronoi diagram for part of the B-line service area is shown in Figure 3.

In Stage 2, each parcel centroid is connected to the closest point on the closest link whose street name is the same as the parcel's street address. The parcel's stop assignment and walking path then simply follows the network Voronoi tree.

The advantage of the two-stage approach is that the network on which shortest path trees are built is smaller, not having any demand nodes. However, this approach presents practical complications such as dealing with duplicate network links and inconsistent street name spelling. In addition, in the networks analyzed, there were only a few parcels per street link, making the efficiency gain too small to justify those complications.

DETERMINING PARCEL-LEVEL DEMAND

Determining transit demand at each parcel is essentially a matter of distributing stop-level on-off counts over the parcels in a stop's service area. This approach takes advantage of the demand information contained in available on-off counts.

Distribution over parcels follows the standard principles of trip distribution. Productions (matched to on counts) are distributed separately from attractions (matched to off counts). Each parcel k has a certain power to produce and attract trips based on its land use type and an appropriate measure of the parcel's size as discussed earlier, modified by distance from a stop and competition from other transit lines:

$$\text{onstrength}_k = \text{size}_k * \text{oncoef}(LUC_k) * \text{propensity}_k * \text{compfactor}_k \quad (3)$$

$$\text{offstrength}_k = \text{size}_k * \text{offcoef}(LUC_k) * \text{propensity}_k * \text{compfactor}_k \quad (4)$$

where

LUC_k = parcel k 's land use code,
 size_k = value of its size attribute, and
 $\text{oncoef}(LUC_k)$ and
 $\text{offcoef}(LUC_k)$ = trip production and trip attraction coefficients, respectively, for LUC_k .

(The variables propensity_k and compfactor_k are explained later.) To illustrate, suppose parcel k is three-family residential. In the Boston data set, the size attribute used for residential properties is net living area, and so size_k is the parcel's net living area (ft^2), and $\text{oncoef}(LUC_k)$, the trip production coefficient, has units of trips per ft^2 of net living area. In the Albany area, however, the parcel database includes the population of residential properties, which was judged to be a better size attribute for determining transit demand. Therefore, for a three-family parcel in Albany, size_k is parcel k 's population, and $\text{oncoef}(LUC_k)$ has units of trips per person. Later, this paper describes how production and attraction coefficients were developed.

With the set of parcels in each stop's service area known, and each parcel's onstrength and offstrength calculated, a stop's on counts are then distributed over its parcels in proportion to onstrength , and its off counts in proportion to offstrength . Therefore, it is the relative, not absolute, values of the production and attraction coefficients that matter.

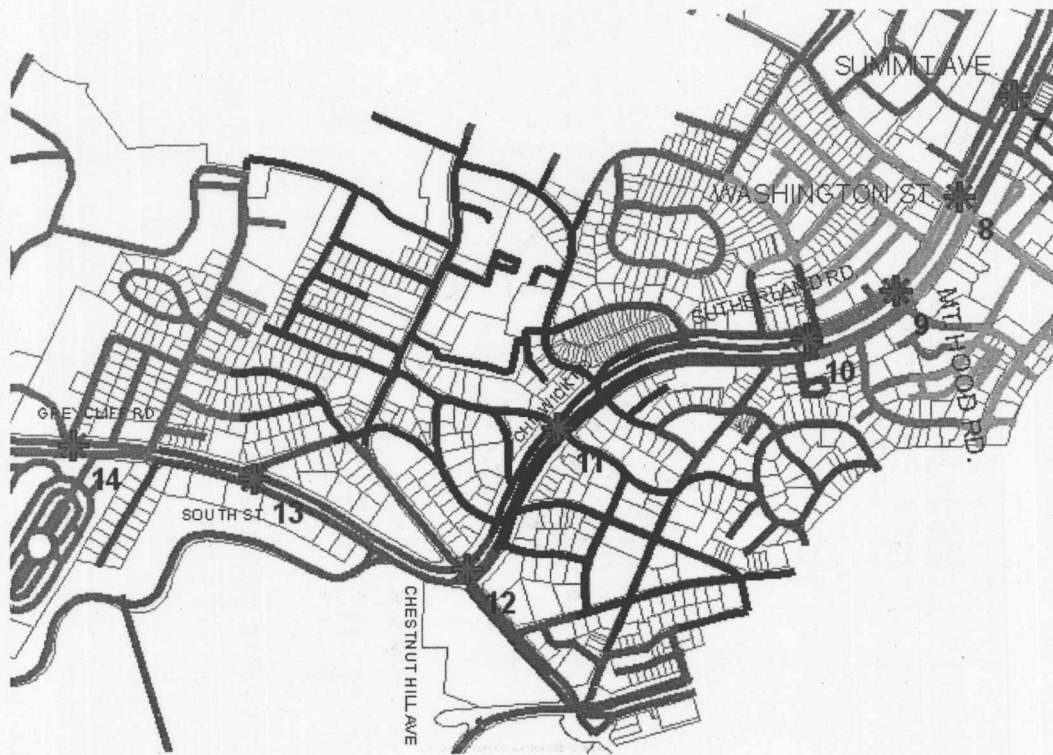


FIGURE 3 Network Voronoi diagram for B-Line outbound elightings.

Trip Production and Attraction Coefficients

The trip distribution approach demanded a set of transit production and attraction coefficients for different land use types, size attributes, and times of day. As a starting point, trip generation rates from the Institute of Transportation Engineers (ITE) publication *Trip Generation* (8) were multiplied by fraction exiting (for oncoef) or entering (for offcoef). Recognizing that different land uses have different transit shares, the authors converted these ITE rates into transit trip generation rates by multiplying by the transit mode share for the most closely allied trip purpose, with mode share data by purpose and time of day obtained from Boston's regional planning agency. Where land use types in the parcel database encompass several ITE categories, ITE rates in the constituent categories were averaged, weighted by a (subjective) estimate of the relative presence of each category in the area. Where the ITE rates used a different size attribute than the parcel data, they were adjusted by the ratio of the means of the size attributes, with mean values found in various demographic or land use databases. Some expert judgment was also used; for example, a high transit share was assigned to high schools and a low transit share to elementary schools, reflecting Boston area travel-to-school customs.

Coefficients for a host of land uses were developed in this manner. An example, for the land use "residential condominium," is illustrated in Table 1. It combines three land use categories from *Trip Generation*. Coefficients were developed for three different size attributes: population (also called household members), living area, and units. Looking at any of the three final sets of coefficients, one can see, for example, how in the a.m. peak, the production coefficient is greater than the attraction coefficient, while the reverse is true in the p.m. peak. Coefficients for schools (not shown in the table) show the opposite pattern.

Although this method of determining production and attraction coefficients is admittedly crude, it still captures the essence of the parcel-level approach. The goal is not to accurately predict demand from each and every parcel; that would be impossible. Using this approach in a stop spacing study, the result will be to favor stop locations that better serve parcels that are expected, by virtue of their size and land use type, to have higher transit demand.

Propensity and Competition Factors

A few studies, summarized in Kittleson & Associates et al. (9), suggest that transit demand decreases at greater distance from a stop. Accordingly, Equation 4 includes the term propensity_k, a function of a parcel's distance from the closest stop. A simple propensity function, often used in gravity models, is exponential:

$$\text{propensity}_k = \exp(-bd_k) \quad (5)$$

where d_k is the distance from parcel k to the nearest stop and b is a parameter. For this study, $b = 4.77/\text{mi}$, which makes the propensity at 0.25 mi one-third the propensity at 0.02 mi. The effect of travel propensity can be seen in Figure 2, where differences in parcel-level demand (indicated by size of the parcel marker) are due in part to distance from the stop. Although crude, this propensity model still seems superior to the traditionally used abrupt step function in which propensity is 1 out to a certain distance from the route (say, 0.25 mi) and 0 after that.

Route competition can also play an important role in how a stop's demand is distributed over its service area. If, for example, one side of a stop's service area is served by a competing transit line while the other side is not, that competition is likely to shift demand in favor of the part of the service area that has no competition. While this effect can be modeled in great detail as a network assignment problem, for an isolated route study, the authors took the simple approach of including in Equation 5 a competition factor that can be set by the analyst in different parts of the route's service area to reflect the fraction of transit demand in that part of the service area that is drawn away to other transit lines. For example, along the B-line, the area south of the Chestnut Hill Avenue stop was assigned a competition factor of 0.4 because it is close to two other branches of the Green Line that offer quicker routes to downtown.

EVALUATION FRAMEWORK

Alternative sets of stops are compared against the base set in terms of passenger walking time impact, passenger riding time impact, and operating cost impact, which is assumed to be proportional to route running time. Because demand and running time data relate to the base set of stops, the base case must first be analyzed to determine each parcel's demand using the trip distribution logic presented earlier; base case walking time is determined at the same time. Riding time and cycle time are known directly from base case data. Base case analysis is also needed to determine an unstopped running time profile, by subtracting expected dwell time at each stop from the (given) base case running time. An additive dwell time model was used:

$$\text{dwelltime}_i = [1 - \exp(-\text{ons}_i - \text{offs}_i)] * a_{oi} + \text{ons}_i * a_1 + \text{offs}_i * a_2 \quad (6)$$

where

- i = stop,
- ons_i and offs_i = on per trip basis,
- a_1 and a_2 = unit boarding and alighting times, respectively, and
- a_{oi} = lost time associated with stopping at i .

The term in brackets is the probability of stopping based on a Poisson passenger arrival process. Accounting for the probability of stopping reduces much of the benefit of eliminating little used stops. If most trips do not stop there anyway because demand is small, how can there be much benefit from eliminating the stop?

While a_1 and a_2 are the same for every stop, the lost time parameter a_{oi} is stop specific and can account for the presence of traffic control (lost time is smaller if the bus has to stop anyway) and hills (lost time is greater on upgrades because of buses' limited power to accelerate). A detailed examination of the impacts of traffic control and grade on stopping delay and its impact on optimal stop location is found in Furth and SanClemente (10). In the present case studies, the authors used a larger value of a_{oi} at stops with no traffic control than at stops where the bus or train, if not stopping, would continue at full speed.

An alternative set of stops might involve removal, insertion, or relocation of stops that exist in the base case. For a given set of stops, the network analysis methods described previously are used to determine each stop's service area and shortest path walking tree, from which follow the walking time impact and each stop's demand (ons, offs). Note that when an alternative is analyzed, parcel demand is held fixed; trip distribution is performed for the base case only. From

TABLE 1 Developing Production and Attraction Factors for Residential Condominiums

ITE LUC	LUC	Size Measure	ITE Rates				ITE Directional Distribution				Transit Share	Weight	Size Measure	Production and Attraction Factors			
			a.m.		p.m.		a.m. Peak		p.m. Peak					a.m. Peak		p.m. Peak	
			a.m.	p.m.	Entering (offs)	Exiting (ons)	Entering (offs)	Exiting (ons)	Entering (offs)	Exiting (ons)				On Coef.	Off Coef.	On Coef.	Off Coef.
CM 230	Res. condo, townhs	/HH member /1,000 sf /Unit	0.2	0.2	0.2	0.2	0.8	0.8	0.7	0.3	0.35	0.16	/HH member /1,000 sf /Unit	0.0089	0.0017	0.0044	0.0090
231	Low-rise res. condo	/HH member /1,000 sf /Unit	0.4	0.5	0.2	0.2	0.8	0.8	0.7	0.4	0.5	0.5	/HH member /1,000 sf /Unit	0.0160	0.0033	0.0081	0.0157
232	High-rise res. condo	/HH member /1,000 sf /Unit	0.2	0.2	0.2	0.2	0.8	0.8	0.7	0.3	0.3	0.18	/HH member /1,000 sf /Unit	0.0202	0.0044	0.0106	0.0197
CM—cumulative			0.4	0.4	0.2	0.2	0.8	0.8	0.5	0.5	0.55	0.17	/HH member /1,000 sf /Unit	0.0176	0.0036	0.0108	0.0117
			0.5	0.5	0.2	0.2	0.8	0.8	0.5	0.5			/HH member /1,000 sf /Unit	0.0310	0.0064	0.0190	0.0206
			0.2	0.2	0.2	0.2	0.8	0.8	0.7	0.3			/HH member /1,000 sf /Unit	0.0396	0.0081	0.0242	0.0263
			0.3	0.3	0.2	0.2	0.8	0.8	0.7	0.3	0.10	0.18	/HH member /1,000 sf /Unit	0.0023	0.0005	0.0010	0.0021
			0.3	0.4	0.2	0.2	0.8	0.8	0.7	0.3			/HH member /1,000 sf /Unit	0.0040	0.0008	0.0017	0.0036
											1.00	0.17	/HH member /1,000 sf /Unit	0.0051	0.0010	0.0022	0.0047
													/HH member /1,000 sf /Unit	0.0288	0.0058	0.0162	0.0227
													/HH member /1,000 sf /Unit	0.0511	0.0105	0.0288	0.0399
													/HH member /1,000 sf /Unit	0.0649	0.0136	0.0370	0.0506

CM = condominium, HH = household, sf = square feet.

the stop-level on-off results, the route's load profile follows. Expected dwell time is calculated for each stop using Equation 6; added to the unstopped running time profile (interpolated if need be for inserted or relocated stops), it yields the new running time profile, from which the riding time and operating cost impacts are readily determined. The walking, riding, and operating cost impacts can be combined using a chosen set of unit costs to yield an overall societal cost of alternative as a basis for comparison and optimization.

This analysis should be performed for multiple periods of the day and aggregated, because stop location changes will affect not only peak periods but the whole day. A reasonable approach is to evaluate a few representative periods and scale the results to represent a full year's operation.

For many studies, it is desirable to focus on only part of a route, because stop location impacts are quite local. For a pair of alternatives to be comparable, it is important that they account for exactly the same set of parcels. One option is to arbitrarily determine the last stop's service boundary. A more exact approach allows service area boundaries to be determined internally. However, this approach requires that the stop set for every alternative includes the same two final stops at each segment end; the boundary between those stops then serves as the analysis area boundary, and impacts at the outer ("external") stop are ignored. Care must be taken to ensure that this external stop does not share a boundary with any stop that is added or eliminated in any of the alternatives.

One minor but interesting finding of these studies was that stop consolidation yields a small riding time savings beyond the savings attributed to a reduction in lost time due to stopping. It stems from the fact that for passengers boarding at a given stop, time spent waiting for others to board or alight at that stop does not count as riding time, and while it takes place during a period reckoned as waiting time, it does not increase average waiting time. To illustrate, suppose lost time per stop is 10 s, unit boarding time (a_1) is 4 s per passenger, 5 passengers each board at Stop 11 and at Stop 12; when Stop 12 is eliminated, the Stop 12 passengers will shift to Stop 11. Before Stop 12 was eliminated, the Stop 11 passengers' riding time included 30 s at Stop 12, consisting of 10 s of lost time and 20 s for passengers to board. With consolidation, running time on the route falls by 10s; however, to the original Stop 11 passengers, riding time falls not just by 10 s, but by 30 s. The extra 20 s of dwell time at Stop 11 simply shifts departure times at Stop 11, but does not affect the headway, leaving waiting time there unchanged. Therefore, in addition to reducing lost time, stop consolidation also offers a small

reduction in passenger travel time proportional to the increase in the number of passengers boarding and alighting per stop.

CASE STUDY RESULTS

The first case study concerns the 2.7-mi western section of the B-line, a branch of the Massachusetts Bay Transportation Authority's (MBTA's) light rail Green Line that operates in a reservation along Commonwealth Avenue in Brighton. The study section has 15 stops between Boston College (the outer terminus) and Packard's Corner, near Boston University.

In an effort to speed operations on the B-line, the MBTA proposed four stops for elimination based on a simple rule of thumb: the four stops with the least daily boardings, subject to the constraint that they would not eliminate two consecutive stops. Because of strong public reaction, the Summit Avenue stop was dropped from the list, and the other three stops were eliminated on a trial basis.

Although this model was not ready in time to support the MBTA's decision process, the authors still pursued the B-line as a test case. On-off and running time data were obtained for a.m. peak, p.m. peak, and midday operations, which were modeled in both directions. Annual impacts were determined by letting the a.m. peak, p.m. peak, and base periods represent 10, 15, and 70 h per week, respectively. Because the four stops originally proposed for elimination are far enough apart, the impacts of eliminating each stop are independent and can simply be aggregated.

Annual impacts of eliminating the four stops are shown in Table 2. Results are shown both per trip (taking a weighted average over the three periods and two directions analyzed) and per year. "Passengers affected" are those who in the base case walked to or from a stop that was eliminated.

As can be seen from Table 2, impacts vary considerably between the four stops proposed for elimination. Overall, the results confirmed the MBTA decision: it was found that removal of Greycliff, Mt. Hood, and Fordham would be beneficial, while elimination of Summit would incur a net increase. The impact at Greycliff is quite small because it has little demand. Its elimination offers only a tiny riding time benefit, for two reasons: its small demand makes the probability of stopping there small, and being near the end of the line, it has few through passengers. Removal of Summit Avenue incurs too great a walking cost to justify the riding cost and operating cost benefit.

TABLE 2 Annual Impacts of Eliminating B-Line Stops

	Unit Cost (\$/h)	Eliminate Stop 14 (Greycliff)	Eliminate Stop 9 (Mt. Hood)	Eliminate Stop 7 (Summit)	Eliminate Stop 2 (Fordham)
Passengers affected (pax/trip)		0.8	2.2	5.2	6.0
Change in walking time (pax-min/trip)		0.3	4.3	10.1	2.1
Change in riding time (pax-min/trip)		-0.2	-7.4	-6.9	-4.5
Change in one-way running time (min)		-0.02	-0.23	-0.26	-0.05
One-way trips/week	1,650				
Change in walking cost (\$/yr)	\$12	5,816	74,230	172,670	35,965
Change in riding cost (\$/yr)	\$6	-1,861	-63,285	-58,962	-38,196
Change in operating cost (\$/yr)	\$282	-8,513	-90,696	-103,295	-20,893
Total change in societal cost (\$/yr)		-4,558	-79,750	10,412	-23,124

pax = passengers.

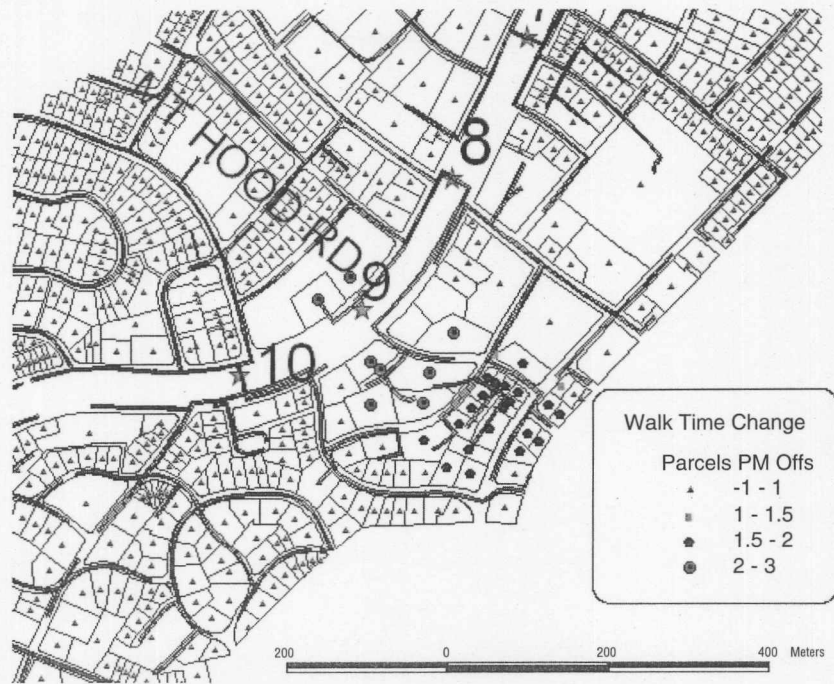


FIGURE 4 Walking time changes and new walking paths for parcels affected by elimination of Mt. Hood Road.

Given the political nature of transit route planning, citizens and planners are interested not only in average or overall impacts, but in disaggregate impacts as well. On the advice of MBTA planners, the authors developed a graphic that shows, for every parcel, how much farther passengers will have to walk. In Figure 4, parcels in the neighborhood of Mt. Hood Road are coded to indicate how much their walking time will increase if that stop is eliminated. The greatest individual impact is to eight parcels whose walking time increases by 2 to 3 min—no wonder that the proposed elimination of this stop generated little political opposition.

The second case study dealt with Capital District Transit Authority (CDTA) Route 55. Because parcel data were not readily available within Albany city limits, the study was limited to the 6 mi between the Albany city line and the western end of the route in downtown Schenectady, a section with 45 eastbound stops and 42 westbound stops. CDTA planners were interested in increasing running speed by consolidating stops. (This effort was independent of an effort to introduce limited-stop bus rapid transit in the corridor.) A consultant, using rules of thumb that targeted low ridership stops while constraining interstop distance, recommended 6 eastbound and 9 westbound stops for elimination (this proposal is called Alternative 1). Based on a GIS analysis, the authors developed Alternative 2, respecting the same constraint on interstop spacing while seeking to minimize societal cost. This alternative included one stop relocation as well as several stop eliminations and attempted to locate stops closer to demand concentrations.

Results, shown in Table 3, combine two directions and four representative periods, appropriately scaled. Based on the unit costs (\$5/h for riding time, \$10/h for walking time, and \$80/h for operating cost), Alternative 1 did more harm than good, causing an increase in walking cost that was not fully compensated by reductions in riding time and operating cost. Alternative 2, on the other hand,

reduced overall cost. However, the impact is small, largely because of the small demand at the affected stops.

CONCLUSION

Given the widespread interest in stop spacing as a means of improving transit efficiency, and given the political context in which transit systems operate, methods for predicting impacts of stop location changes are needed. Geographical databases and GIS tools offer a means not previously available for analyzing stop location changes.

The software that the authors developed for stop spacing analysis (NeuStopSys) runs on the ArcView platform and has been made available at nominal cost through the University of Florida's McTrans Center in Gainesville. Given that this was only a proof-of-concept study, the software is not easy to use and would probably require considerable additional coding effort for application with a particular city's parcel database. It is hoped that easy-to-use tools following this

TABLE 3 Evaluation of Alternative Stop Sets for CDTA Route 55

	Base Case	Alternative Stop Set 1	Alternative Stop Set 2
Number of stops eastbound	45	39	36
Number of stops westbound	42	34	34
Change in walking cost (\$/yr)	—	21,883	15,784
Change in riding cost (\$/yr)	—	-9,636	-12,732
Change in operating cost (\$/yr)	—	-10,137	-12,021
Change in total societal cost (\$/yr)	—	2,110	-8,969

approach will be developed in the near future and become part of the practice of transit planning.

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