Empirical Analysis of the Effects of Bus Stop Consolidation on Passenger Activity and Transit Operations

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Abstract

This paper analyzes changes in passenger passenger activity and operating performance following implementation of a bus stop consolidation project at TriMet, the regional transit provider for the Portland, Oregon metropolitan area. The study makes extensive use of archived bus operations and passenger activity data from TriMet's automated bus dispatching system. Focusing on one of the first routes where stop consolidation has been implemented, changes in passenger activity and operating performance in route segments where stop consolidation occurred were related to changes in adjacent route segments where stops were not consolidated. The findings indicate that bus stop consolidation had no significant effect on passenger activity, while bus running times improved by nearly six percent. Running time improvements may have been limited by insufficient schedule adjustments.

Introduction

The location and spacing of bus stops is one of the most important elements of the transit service planning process. Both the budgetary resources of the transit provider and the travel times of passengers are affected by the spacing of stops. The trade-offs involved in deciding on stop spacing may appear to be straightforward (i.e., minimizing the transit provider's operating costs versus maximizing passengers' access to service), but the reality is more complex. Consider the following expected consequences of increasing the distance between bus stops on a hypothetical route:

1. Bus running times will decline, reducing operating costs that can, in turn, be translated into additional service for a given operating budget;

2. The variation in bus running time will decline, saving the transit provider wasted service capacity (in the form of excess recovery and layover, as well as from uneven spacing of buses) and saving passengers excess waiting time;

3. Passengers' access and egress times required to travel to stops and from stops to destinations increase, while their in-vehicle travel times decrease.

Commonly, only the third consequence is emphasized in the literature on bus stop planning. For example, the *Transit Capacity and Quality of Service Manual* states that the determination of the appropriate spacing between bus stops "… involves trade-offs between the convenience of passengers using a … stop, and those passengers already aboard a bus who are delayed each time a bus stops" (Kittleson and Associates et al., 2003). Although the effects of stop spacing on service reliability and passenger waiting times are fairly well understood (e.g., Bowman and Turnquist, 1981; Sterman and Schofer, 1976; Turnquist, 1978), they are not generally considered in the service planning and evaluation literature (Benn, 1995). This is surprising, given that waiting times represent the most onerous time component of the transit journey, as evidenced by estimates that the marginal value of waiting times exceeds in-vehicle times by a factor of three (Mohring et al., 1987).

Analysis of the relationship between stop spacing, service utilization, and operating performance has traditionally been hampered by the cost and difficulty of manual data collection. Thus, analytical and simulation approaches have frequently been used to study the stop spacing problem (e.g., Furth and Rahbee, 2000; van Nes and Bovy, 2000; Vuchic and Newell, 1968; Wirasinghe and Ghoneim, 1981). However, with the increasing deployment of automatic vehicle location (AVL) and automatic passenger counter (APC) technologies, the costs of recovering data on transit operations and passenger activity have plummeted. It is now possible to empirically analyze the effects of changes in stop spacing on operating performance and passenger activity using archived data from these systems.

This paper examines the changes in operating performance and passenger activity associated with a bus stop consolidation program at TriMet, the transit provider for the Portland, Oregon metropolitan area. The objective of the program was to improve service reliability and vehicle running times by increasing the spacing between bus stops, while minimizing patronage losses from reductions in stop accessibility. Our analysis concentrates on an interlined route that was part of the agency's stop consolidation program. Drawing on archived data from TriMet's automated bus dispatching system (BDS), we examine passenger activity and operations performance in segments of the route that were subject to stop consolidation, and identify the changes that occurred following consolidation. Changes on segments where consolidation occurred are also compared to changes on other segments of the study route where stop locations did not change. Thus, our approach has the characteristics of an experimental design.

The remainder of the paper is organized as follows. In the next section, we discuss the service planning literature on stop spacing standards. This is followed by a review of the literature covering the relationship between stop spacing, service reliability, and utilization. TriMet's stop consolidation program and the subject route of the study are then briefly described. The research design and the results of the empirical analysis are then presented. Finally, the concluding section of the paper discusses the implications of our findings.

Bus Stop Spacing in the Transit Industry

Most transit providers have developed bus stop spacing standards to support service planning activity. Benn's (1995) survey of the transit industry found that 85% of the responding properties had adopted stop spacing standards, a substantial increase over the 62% who responded similarly a 1984 survey. That stop spacing standards are increasingly common in the transit industry likely reflects the often-intense conflict surrounding the location and spacing of stops. Furth and Rahbee (2000: 15) observe that “(o)ne purpose of stop spacing guidelines is to give transit agencies an objective way to resist the pressure to add unnecessary stops or eliminate stops.”

Athough stop spacing standards are common, the standards themselves are hardly uniform. Benn (1995: 13), for example, concludes that “(t)here are as many practices as there are operators.” Even within transit agencies, stop spacing standards can encompass fairly broad distance ranges, providing service planners with considerable latitude, but also exposing the agency to greater outside pressures. Table 1 summarizes stop spacing standards from three industry-level reports (Benn, 1995; NCHRP, 1980; TTI, 1996) and from TriMet’s (1989) service planning guide. Generally, the distance between stops is inversely related to the density of development (which proxies demand), ranging from about every other intersection in Central Business Districts to as much as one-half mile in low-density settings. Even within given categories, however, the stop spacing range is fairly substantial. This is particularly evident in lower density rural settings, where the standards could yield as few as two or as many as 12 stops per mile.

Table 1: Selected Bus Stop Spacing Standards

Service Environment	TriMet	TCRP Rpt. 19	TCRP Syn. 10	NCHRP Syn. 69
High density (80+ units/acre, CBD)	400-600 ft.	300-1,000 ft.	--	440-528 ft.
Non-CBD	--	--	650-875 ft.	--
Fully developed resid. (22-80 units/acre)	500-750	500-1,200	--	660-880
Low density residential (4-22 units/acre)	600-1,000	600-2,500	--	1,056-2,640
Rural (less than 4 units/acre)	"As Needed"	650-2,640	--	1,320-2,640

Furth and Rahbee (2000) observe that stops in northern European cities are spaced much further apart than in comparable U.S. 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 3-4 per mile compared to the U.S. practice of 7-10 per mile. One possible explanation for the closer spacing of stops in the U.S. may be related to the source of operating subsidy. In contrast with European systems, whose operating subsidies are provided from national sources, U.S. transit systems rely on state and local sources for their operating support. This distinction may contribute to the greater emphasis on maximizing service coverage and access in U.S. transit systems (Sale and Green, 1979) versus a greater emphasis on maximizing operating efficiency in European systems.

The relatively high density of stops in U.S. transit systems results in accessibility levels where it is not uncommon for many transit riders to be within walking distance (usually defined to be one-quarter mile) of several stops. Thus, while elimination of stops can result in lower accessibility for some passengers, the aggregate reduction in accessibility from stop consolidation can be fairly small. For example, Benn (1995) cites a 1992 study by MTA New

York City Transit in which the distance between stops was increased by over 40%, but the resulting accessibility declined by only 12%.

Bus Stop Spacing, Service Reliability, and Transit Utilization

From the perspective of a transit provider, optimal transit service can be characterized by a limited number of stops with high and predictable passenger activity and few service reliability problems. Passengers prefer that buses arrive promptly at stops that are spaced such that access, egress, and waiting times are minimized (Murray, 2001). Passengers also seek to minimize their combined in-vehicle and out-of-vehicle travel times, with the latter carrying a higher implicit monetary penalty (Kemp, 1973; Lago & Mayworm, 1981; Mohring et al., 1987; Pushkarev & Zupan, 1977). Out-of-vehicle times are influenced by stop accessibility as well as by service reliability, which impact passenger wait times at stops (Abkowitz & Tozzi, 1987; Bowman & Turnquist, 1981; Turnquist, 1978, 1981). Service reliability problems also affect in-vehicle times in the form of increased bus running times (Koffman, 1990; Levinson, 1983; Strathman et al, 2002; Wirasinghe & Ghoneim, 1981). Thus, bus stop spacing, patronage, and service reliability are inherently linked.

Previous research on bus stop spacing and location has been primarily analytical in nature. The earliest work focused on simple hypothetical service environments, while more recent efforts attempts to simulate conditions representing actual routes or service environments using analytical optimization models and programming methods (Furth & Rahbee, 2000; Murray & Wu, 2003; Saka, 2001; van Nes and Bovy, 2000; Vuchic and Newell, 1968; Wirasinghe & Ghoneim, 1981).

The work of Vuchic and Newell (1968) represents a pioneering effort. They defined the stop spacing problem in terms of transit users' time minimization, and their analysis evaluated the trade-offs between access and in-vehicle times with respect to the distance between stops. They demonstrated that the density of stops should increase monotonically with density of demand along a route, and decrease monotonically with the number of people on board. Optimal stop spacing was represented as the distance at which marginal changes in transit users' access and in-vehicle times were equalized. Given uniform population density, Vuchic and Newell then mathematically derived stop spacing for a hypothetical route. Their results demonstrated that service with larger vehicle capacities and passenger loads (such as commuter rail) is best designed with few stops, where feeder service could be used to concentrate passenger movements.

Subsequent work on stop spacing broadened the scope of the problem to include transit operating costs. Wirasinghe and Ghoneim (1981), for example, defined optimal spacing as a minimization problem with respect to passenger access, egress, and in-vehicle time costs, as well as transit operating cost and the cost of building and maintaining stops. As one would expect, the addition of stop-related costs and operating costs yielded greater optimal distances between stops than solutions based solely on passengers' travel time minimization. Saka (2001) extends this line of research a step further by translating the improvements in operating speed from optimal stop spacing to the corresponding reduction in fleet size and capital cost savings.

More recent work on stop spacing has turned to analytical and mathematical simulation using representative time and monetary values for passengers and transit providers. Work by van Nes and Bovy (2000), for example, focuses on conditions that are representative of transit systems in the Netherlands. They derive optimal stop spacing distances for a large and small city, taking into account passengers' access, waiting, and in-vehicle times, as well as the transit provider's operating costs and revenues. Their simulation also explicitly considers the effects of access and service frequency on the demand for transit. van Nes and Bovy derive optimal spacing distances for a variety of alternative scenarios, ranging from the simple access/in-vehicle time minimization problem posed by Vuchic and Newell to a comprehensive joint cost minimization solution for the full set of passenger and operator variables. Their findings in the latter case yielded optimal stop spacing distances of 600 meters for the small city case and 800 meters for the large city case. These distances were about twice as great as the observed distances in selected systems in the Netherlands and other western European cities.

Furth and Rahbee (2000) employed a dynamic programming approach to determine the optimal number and location of bus stops for a heavily-utilized route in the Massachusetts Bay Transportation Authority (MBTA) system. Using the route's historic stop-level patronage data and a geographic information system (GIS), they first allocated boardings and alightings from each stop on the route to parcels in the route corridor. This provided a representation of the spatial distribution of demand in the corridor. Then, through dynamic programming, they determined the number and location of stops in the corridor that minimized passenger's total time costs and MBTA's route operating costs, given assumed values of walking and riding time, operating costs and other operating factors. Compared to existing service with 37 bus stops, the programming results identified 19 stops, with several at new locations. Average spacing was found to increase from approximately 200 to 400 meters. Passengers' average walking time increased .60 minutes, but their in-vehicle times declined 1.8 minutes. Average vehicle running times declined 4.3 minutes. Under the optimal stop spacing solution, the combined savings to passengers and the MBTA totaled $132 per hour.

Analytical studies of optimal bus stop spacing have provided valuable insights regarding the complex trade-offs involved in planning service in the context of multiple objectives. The findings from this research, particularly from more recent work that closely approximates the actual operating environments of transit systems, consistently indicates that bus stops are too closely spaced and that consolidation is thus warranted. The authors are aware of considerable anecdotal evidence of stop consolidation efforts underway in U.S. transit systems. These efforts may be responding to the accumulating evidence reported in the literature, and they may also be motivated by the gradually worsening traffic congestion that is eroding speeds and degrading reliability in many transit systems. Whatever the reason, the elimination or relocation of bus stops is among the most contentious activities that transit planners are likely to encounter. While analytical evidence provides helpful guidance and some justification for this activity, actual empirical evidence linking stop spacing, reliability, and utilization is lacking.

TriMet's Bus Stop Consolidation Program

TriMet provides bus service to the Portland region on a 93-route system that covered 1,460 directional miles with 8,190 designated stops in 2001. At the system level, average bus stop spacing in 2001 was approximately 940 feet. Average daily boardings in 2001 were nearly 180,000, or about 22 boardings per stop.

Like many urban transit providers, TriMet has faced a growing challenge in its efforts to deliver reliable and timely bus service over a regional road system that has become increasingly congested. The Portland region grew rapidly during the 1990s. The region's annual population growth rate over the decade slightly exceeded two percent, while its annual rate of growth in vehicle miles of travel (VMT) was just under five percent. Given that roadway capacity grew at about half the rate of VMT, the region's travel time index expanded at a near-two percent rate and its ranking among the metropolitan areas covered in the Texas Transportation Institute's annual mobility reports fell from 25th in 1990 to 10th in 2000 (Schrank and Lomax, 2004).

The threats to transit service delivery associated with worsening traffic conditions, however, were substantially mitigated by the TriMet's adoption of advanced technologies in the 1990s. In 1998, the agency implemented a new automated bus dispatching system (BDS), which included GPS-based AVL technology and more widespread deployment of APCs (the latter being first introduced in the early 1980s). The BDS provided bus operators with real time information on schedule adherence, while extensive archived operations and passenger data provided operations managers, field supervisors, service planners, schedulers, maintenance managers, and market researchers with the information they needed to adapt to changes in the operations environment. Thus, despite worsening conditions in the 1990s, a number of service performance and quality indicators (e.g., on-time performance, running times, headway maintenance, recovery/layover requirements) had either stabilized or improved over the latter part of the decade (Strathman et al., 2000). In light of these outcomes, TriMet has been recognized as a transit industry leader for its ability to recover data with advanced technology and to effectively translate that data into higher quality and more efficient bus service (Furth et al., 2003).

Following its initial efforts focusing on the use of BDS data to improve operations, TriMet turned its attention to the more basic question of route design, including the location and spacing of bus stops. In 1999 the agency launched its Streamline project. The stated goal of the project was to "…improve service reliability and reduce travel time while also improving patron safety, accessibility and comfort on select routes" (TriMet, 2002: 27). An objective related to this goal was to reduce operating costs while maintaining service frequency.

Bus stop consolidation and relocation was one of a number of elements included in the Streamline project. Other eligible treatments in the project included signal priority, roadway improvements (e.g., bus only/queue jump/bypass lanes, curb extensions/ramps, intersection/turning changes), enhanced stop amenities (e.g., shelters, benches, lighting, signage, trash cans), on-street parking restrictions, and changes in support of compliance with the Americans With Disabilities Act (ADA). Changes in routing to provide more direct service were also considered.

With respect to stop consolidation, the approach adopted by TriMet service planners in the Streamline project consisted of first breaking down a selected route into segments. A "clean slate" approach was then followed in locating and spacing stops in a segment. The first step was to identify the segment's "anchor" stops at transfer points, major transit trip generators, and major intersections. Once the anchor stops were located, the next step involved the placement of additional stops between the anchor points, following the agency's stop spacing standards. Siting considerations and other circumstances also factored into the process, including:

- general placement of stops at the farside of intersections with signal priority;
- selecting stop locations that are well-connected to pedestrian infrastructure and with easy neighborhood access;
- ensuring that stop locations facilitate safe street crossing;
- preserving stops with a history of regular lift activity;
- locating stops to minimize impacts on traffic delay and traffic safety;
- ensuring compatibility of stops with adjacent properties;

- locating opposing stops in pairs;
- ensuring that stop sites are on level slopes and provide adequate visibility;
- ensuring that stop location decisions reflect input from the public and neighborhood/business associations.

The 4-Fessenden/104-Division, which provides interlined radial service to downtown Portland, was the first product of the Streamline project and is the subject of our analysis. Service on the reconfigured routes commenced in 2000. The 4/104 was among the most heavily patronized routes in the TriMet bus system, with approximately 7,500 weekday boarding rides and over 45 boarding rides per vehicle hour in early 2000. It was also among the lowest performers in reported excess wait time per passenger, an indication of service reliability problems (TriMet, 2000). Figure 1 shows the segments of the 4/104 where stop consolidation and/or relocation occurred. These "treatment" segments are the focus of our analysis. Another set of segments adjacent to each of the treatment segments is also identified in Figure 1. These serve as "control" segments in the analysis, reflecting exogenous changes occurring on the route over time. Thus, the analysis will relate changes observed in the treatment segments to those observed in the control segments.

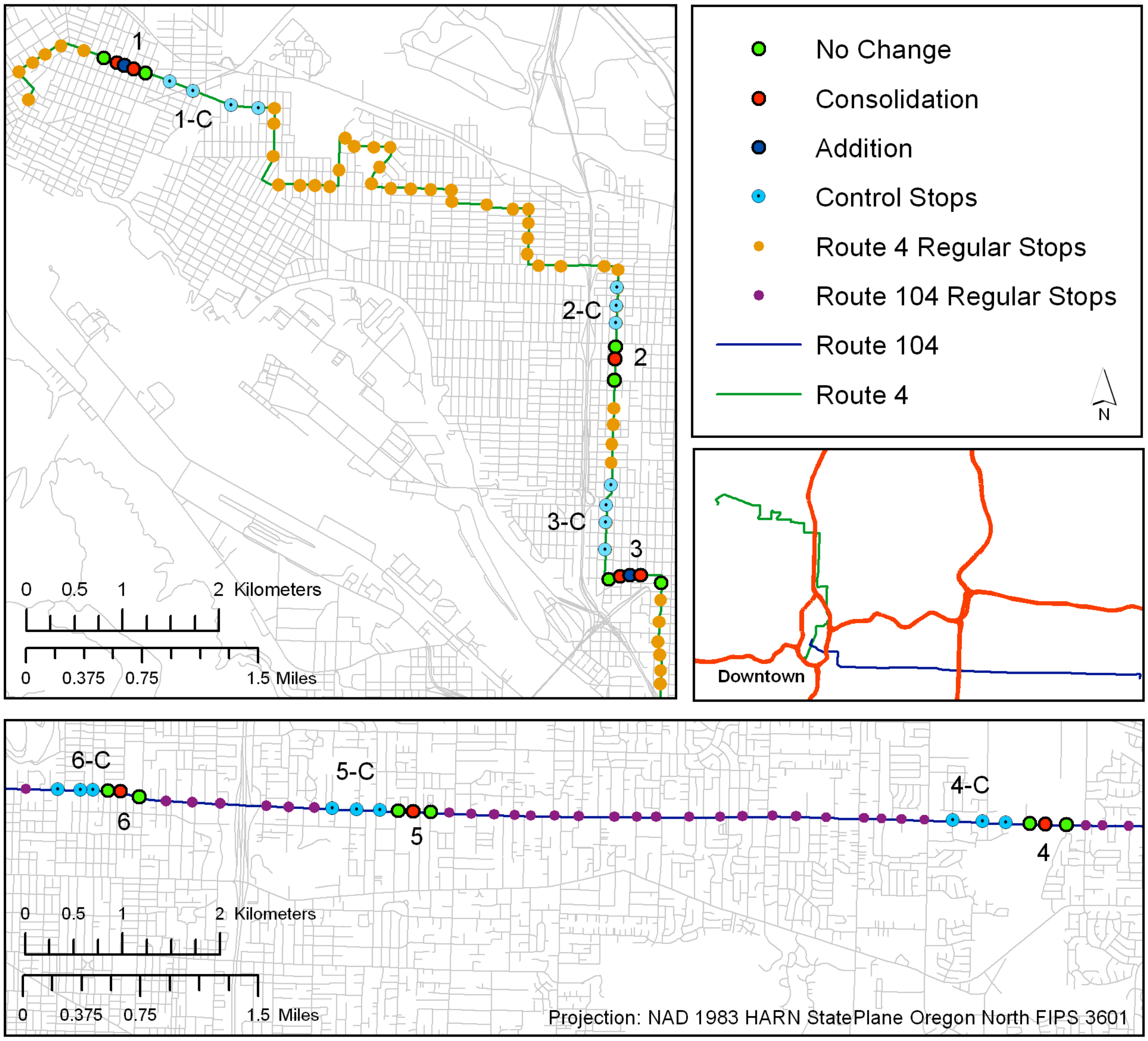

Figure 1: 4-Fessenden/104-Division Stop Consolidation Segments

Table 2 summarizes the stop changes by direction for routes 4/104. The 4-Fessenden had a net reduction of four inbound and six outbound stops, while the 104-Division had a net reduction of five inbound and seven outbound stops. In one instance (i.e., 104-outbound), the reduction simply reflects the elimination of stops, while in the other cases new stops were added from the consolidation or relocation of exiting stops. The net reduction in stops led to an increase in average spacing between inbound stops of more than 6% and an increase of more than 8% between outbound stops.

Table 2: Summary of Stop Changes on Route 4-Fessenden/104-Division

Route	Direction	Stops Before/After	Stops Removed	Stops Added	Av. Spacing Before/After
4	Inbound	67/63	8	4	933/992 ft.
4	Outbound	78/72	8	2	820/890 ft.
104	Inbound	84/79	8	3	839/892 ft.
104	Outbound	95/88	7	0	742/801 ft.

Research Design

The objective of the analysis is to test for changes in passenger activity and operating performance in the route treatment segments (where stop changes were made) relative to changes that occurred in the control segments (where no changes in stops were made). The first step of our approach is to link each scheduled bus trip that occurred before the change with its exact counterpart from the period following the change. This trip matching produces a paired sample, or a two-period panel, which has the advantage of reduced sampling error relative to the alternative of drawing independent samples from each period (Wonnacott and Wonnacott, 1972).

The unit of analysis for the tests is a trip-segment (e.g., passenger activity per trip per segment). Thus, for example, each paired trip will generate *n* treatment observations and *n* control observations, where *n* is the number of route control and treatment segments. Each observation is calculated as the change in the value of a given variable following implementation, or

$$\text{Value change} = \text{Post-implementation value} - \text{Pre-implementation value} \qquad (1)$$

A paired sample t-test is applied to the change to determine statistical significance. The tests are applied to the following variables: boardings, alightings, boardings + alightings, running time, running time coefficient of variation, and headway coefficient of variation.

In addition to the t-tests on changes in passenger activity and operating performance, a set of regressions is run to control for the effects of other factors that could influence bus operations and passenger activity. The general specifications of the regressions are as follows:

Boardings + Alightings = f(Pre-treatment, Post-treatment, Pre-control, Population, Income, D-104, AM-Inbound) (2)

Running Time = f(Pre-treatment, Post-treatment, Pre-control, AM-Inbound, Actual Stops, Boardings, Alightings, Lifts, Schedule Delay, D-104) (3)

CV Running Time = f(Pre-treatment, Post-treatment, Pre-control, CV Actual Stops, CV Schedule Delay, CV Lifts, CV Boardings+Alightings, D-104, AM-Inbound) (4)

CV Headway = f(Pre-treatment, Post-treatment, Pre-control, CV Actual Stops, CV Schedule Delay, CV Lifts, CV Boardings+Alightings, D-104, AM-Inbound), (5)

where

Boardings+Alightings = average of the sum of passenger boardings and alightings per trip-segment;

Running Time = average bus running time (in seconds) per trip-segment;

CV Running Time = coefficient of variation of bus running time (in seconds) per trip-segment;

CV Headway	=	headway coefficient of variation (in seconds) per trip-segment;
Pre-treatment	=	a dummy variable equaling one if the observation occurred in a treatment segment prior to stop consolidation;
Post-treatment	=	a dummy variable equaling one if the observation occurred in a treatment segment after stop consolidation;
Pre-control	=	a dummy variable equaling one if the observation occurred in a control segment prior to stop consolidation;
Population	=	population residing within 1/4 mile of segment bus stops, calculated with GIS from 2000 Census block data;
Income	=	median income of households residing within 1/4 mile of segment bus stops, calculated with GIS from 2000 Census block group data;
D-104	=	a dummy variable equaling one if the trip-segment occurs on the 104-Division;
AM-Inbound	=	a dummy variable equaling one for morning peak inbound trip-segments;
Actual Stops	=	average number of scheduled and unscheduled stops per trip-segment;
CV Actual Stops	=	the coefficient of variation of number of scheduled and unscheduled stops per trip-segment;
Lifts	=	average number of lift operations per trip-segment;
CV Lifts	=	the coefficient of variation of the number of lift operations per trip-segment;

Schedule Delay	=	average delay (in seconds) at the segment origin;
CV Schedule Delay	=	the coefficient of variation of delay at the segment origin;
CV Boardings+Alightings	=	the coefficient of variation of the sum of boardings and alightings per trip-segment.

The three segment dummy variables in each of the regressions are specified to capture the changes in passenger activity, running time, running time variation and headway variation relative to the omitted reference, which are the control segments after the implementation of stop consolidation. The covariates in the regressions are commonly included in empirical studies of the determinants of passenger activity, running time, and service reliability (e.g., Abkowitz and Tozzi, 1987; Levinson and Brown-West, 1984; Strathman et al., 2000, 2002; Turnquist, 1978). For example, we expect that passenger activity will be directly related to the size of the resident population within 1/4 mile of segment stops, and will be inversely related to the level of income in a stop area. Running time is expected to increase with the number of stops made in a segment, lift and passenger activity, and be less for morning peak in-bound trips than out-bound trips in the evening peak. Schedule delay could be either positively or negatively related to running time. If delay is chronic and persistent it is likely to have a positive effect on running time. Alternatively, if delay is circumstantial and operators exploit recovery opportunities, delay could be inversely related to running time. It is hypothesized that variations in running time and headways will be similarly related to variations in the same set of variables that were specified in the running time regression. Finally, we include a dummy variable for the 104-Division to capture differences in passenger activity and operations relative to the 4-Fessenden.

Selective introduction of signal priority was also an element of TriMet's Streamline project, but the phasing of its implementation on the study route prevented us from examining its effects. For example, on some segments of the 4/104, signal priority was implemented prior to or after the study period, while on other segments it was implemented just prior to or just after stop consolidation. We were thus unable to design the analysis to jointly address stop consolidation and signal priority effects. We have assessed signal priority effects on bus operations elsewhere in the TriMet system (Kimpel et al., forthcoming).

The analysis focuses on inbound trips during the morning peak service period (7:00 to 9:00 A.M.) and outbound trips during the evening peak (4:00 to 6:00 P.M.), since these are the conditions that drive the stop planning process (Furth and Rahbee, 2000). Three months of weekday, stop-level passenger activity, service reliability, and operations data were obtained from TriMet's BDS data archive for both the pre and post time periods. The time periods correspond to approximately six months before and six months after bus stop consolidation and relocation took place. Determining the time frame for assessing change relied on judgment, given that there is little empirical evidence of the dynamic consequences of stop consolidation and relocation.

The source data were aggregated to the trip-segment-level. The data were then subjected to a cleaning process to check for errors and missing information (primarily passenger data), and were summarized over all days on a per trip basis in order to generate the individual variables needed for the study. To ensure robustness, a 30-trip observation threshold was set for the calculation of averages and coefficients of variation. This produced 138 total treatment trip-segment 138 total control trip-segment observations.

Results

Table 3 presents the post/pre differences in means for treatment and control trip-segments. The results for three passenger activity and three operations variables are reported. None of the passenger activity variables were found to change significantly for the treatment segments. Among control segments, average boardings per trip segment increased about 10% after implementation of the stop consolidation program. While statistically significant in its own right, the increase in control segment boardings was not found to be significantly greater than the small increase that occurred on treatment segments. In other words, the relative reduction in treatment segment boardings shown in the right hand column of the table was not found to be significant.

Table 3: Treatment and Control Trip-Segment Paired Sample Means Differences

Variable	Treatment Segment Difference	Control Segment Difference	Treatment – Control
Av. Boardings	0.01	0.22*	-0.21
Av. Alightings	0.05	0.00	0.05
Av. Boardings + Alightings	0.06	0.22	-0.16
Av. Running Time	-9.05**	-3.63*	-5.41*
CV Running Time	-0.01	0.01	-0.02
CV Headway	1.10	-4.50	5.61

* Indicates statistical significance at the 90% level.
** Indicates statistical significance at the 95% level.

The most notable change in Table 3 is the reduction in running time that occurred after implementation of stop consolidation. Bus running time on the treatment segments declined by slightly more than nine seconds (or 9.6%), and it also declined by more than three and a half seconds (or 2.9%) on the control segments. The difference between the reductions in the treatment and control segments (5.41 seconds) represents a net 5.7% reduction in running time attributable to stop consolidation. Neither of the variables addressing running time and headway variability exhibited significant change on the study segments over the time frame. Thus, stop consolidation did not lead to a significant improvement in service reliability.

Taken together, the passenger activity and running time results indicate that stop consolidation achieved an intended objective of concentrating passenger movements among fewer stops, thus reducing time lost from deceleration, dwell and acceleration. Also, in this instance, the savings in running time did not come at the expense of a loss in passengers.

The results of the passenger activity and operations regressions are presented in Table 4. Regarding the boardings plus alightings equation, none of the treatment and control trip-segment dummy coefficients are significant. Thus, any changes in passenger movements are attributable to changes in the size and income of the population residing within 1/4 mile of stops on route segments following stop consolidation. In this case, passenger activity is estimated to increase with the size of the accessible population and decrease with the growth in the median income of that population. Given the considerable overlap of the 1/4 mile stop buffers along these segments, however, the elimination of stops has a limited effect in reducing the size of the accessible population. This likely explains why the earlier paired means test found no significant change in passenger movements, while these results demonstrate the general importance of access. Both the route and period/direction coefficients are significant. The 104-Division is estimated to serve about two fewer passengers per trip-segment than the 4-Fessenden, while morning peak in-bound service is estimated to serve just under one less passenger than evening peak out-bound service.

In the running time regression, both treatment dummy coefficients are significant. Given that the other coefficients in the equation account for other determinants of running time, these estimated effects represent the change in running time due to changes in impedance. The regression estimates that treatment segment running times increased 32.4 seconds, while control segment running time decreased 6.4 seconds. Given that treatment and control segments are adjacent to each other, the interpretation that traffic-related factors underlie these estimated changes is probably wrong, and a more likely interpretation is that they are schedule-related.

Although scheduled running times were reduced in conjunction with the elimination of stops on the 4/104, it appears that they were not reduced enough on the treatment segments. It should be noted that nominal running times on the treatment segments did decline, but this was due to a reduction in the number of stops per trip made on those segments (which averaged 3.6 prior to implementation and 2.6 after). Given that the regression estimates that a one-stop reduction leads to a decline in running time of 42.2 seconds, this indicates that about three-fourths (32.4/42.2) of the potential time savings were not realized. This interpretation is reinforced by the fact that in TriMet's bus fleet, each vehicle's status in relation to the schedule is continuously reported on a control head located next to the operator, thus permitting relatively continuous adjustments.

Running times are also estimated to be about 11 seconds shorter per trip-segment during the morning peak period than they are in the evening peak, consistent with previous findings (Strathman, et al., 2000). Passenger processing time is estimate to be just under 5 seconds per boarding and just over 4 seconds per alighting, with lift operations adding about 30 seconds (not significant).

Neither of the regression equation coefficients related to reliability provide much information. Running time variation per trip-segment is estimated to increase with increases in the variation of passenger movements. It is also estimated to be lower during the morning peak period. None of the estimated coefficients of the headway variation equation are significant.

Table 4: Regression Results*

Variable	Boardings + Alightings	Running Time	CV Running Time	CV Headway
Intercept	5.95 (5.18)	-62.66 (-4.94)	.231 (6.55)	.265 (.05)
Pre-treatment	-.384 (-.76)	-12.822 (-3.85)	.035 (1.40)	2.873 (.78)
Post-treatment	-.293 (-.57)	19.561 (4.02)	.019 (.77)	4.656 (1.25)
Pre-control	-.214 (-.47)	6.389 (1.94)	-.006 (-.24)	3.205 (.87)
Population	.001 (2.28)	--	--	--
Income	-.065 (-2.56)	--	--	--
D-104 Division	-2.148 (-4.24)	-.917 (-.26)	-.007 (-.30)	2.287 (.68)
AM-Inbound	-.756 (-2.01)	-10.588 (-2.21)	-.075 (-3.93)	-4.177 (-1.47)
Actual Stops	--	42.214 (12.36)	--	--
Boardings	--	4.758 (6.20)	--	--
Alightings	--	4.194 (3.40)	--	--
Lifts	--	30.026 (.91)	--	--
Schedule Delay	--	-.001 (-.12)	--	--
CV Actual Stops	--	--	.188 (1.10)	-7.587 (-.30)
CV Schedule Delay	--	--	-.0002 (-.19)	.057 (.43)
CV Lifts	--	--	.005 (1.30)	-1.005 (-1.68)
CV Boardings+Alightings	--	--	.056 (4.36)	-.640 (-.34)
R^2	.25	.83	.13	.03
n	276	276	276	276

* t-statistics are reported in parentheses.

Conclusions

In this paper we have empirically analyzed the effects of bus stop consolidation on passenger activity and bus operating performance. The study has made extensive use of archived AVL and APC data recorded at the bus stop level. Passenger activity was found to be unaffected by stop consolidation, while bus running times improved. The regressions suggest that potential gains in running time may not have been realized due to insufficient schedule adjustments.

From the passengers' point of view, the results indicate that the reductions in accessibility from stop consolidation were offset by time improvements in the line haul portion of their trips. Thus, the utility of their trip-making appears to have been unaffected by stop consolidation, while the transit provider gained from efficiency improvements. Finally, although reliability improvements are a commonly expected consequence of stop consolidation, we found no evidence of a change in running time or headway variation in the route segments studied.

The main contribution of this work is in its empirical orientation. While there has been a considerable amount of research on the subject of stop location and spacing, it has relied heavily on analytical or simulation methods. We were unable to find evidence in the literature that was based on actual operating experience. Generally, our results lend support to the claims from prior analytical and simulation studies that stops are too closely spaced and that related service standards ought to be relaxed. Our findings are also consistent with the expected consequences of increasing traffic congestion, which degrades travelers' line haul times, but does not affect their access or egress times.

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