# Understanding the Demand for Bus Transit Service: A New Approach

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### *Abstract*

A better understanding of the demand for bus transit is vital to the provision of efficient and reliable service. The objective of this study is to better understand the characteristics of demand for bus transit service in relation to bus-stop spacing and service reliability. The availability of accurate and robust data is lacking in previous empirical work. This research analyzes changes in passenger demand following implementation of a bus stop Streamline project at TriMet, the regional transit provider in the Portland metropolitan area. The study makes extensive use of archived bus operations and passenger activity data recorded at the level of the individual stop. The findings indicate that bus stop consolidation and relocation have a negligible impact on demand and that improvements in transit service reliability can adequately compensate for the potential loss of passengers resulting from changes in the number and location of stops. A theoretical framework for analyzing demand is presented to help transit planners better understand the consequences of proposed service changes on ridership.


### *Introduction*

The spacing of bus stops should be guided by the principle of maximizing net social benefit, which includes the effects of spacing on both passengers and transit providers. The primary goal of transit planning is to maximize ridership subject to various budgetary and social welfare constraints. Transit planners may seek to increase ridership by providing new service to previously unserved areas; by providing more frequent service to existing areas; by providing more efficient service types (e.g. limited and express service); by making service more accessible through the addition of new stops; or by providing amenities at bus stops. The elimination of service through stop consolidation or relocation may result in a loss of ridership, particularly with respect to choice riders who have access to more than one travel mode. Captive riders, on the other hand, may still choose use the service, even though accessibility is degraded. If stop consolidation is accompanied by an improvement in service reliability, agencies may experience an increase in demand from choice riders. Certain bus stop locations are more ideal than others in relation to bus stop consolidation or relocation, particularly with respect to the minimization of adverse impacts to existing riders. With bus stop relocation, there also exists the potential to attract new riders due to changes in relative accessibility as previously unserved area will now have more accessible transit. In this paper we empirically analyze changes in passenger demand resulting from a bus stop Streamline project at TriMet, the regional transit provider in the Portland metropolitan area. The analysis is based on a pre-post study design with the two samples being approximately one year apart in time. A methodology is presented that will allow service planners to better predict changes in ridership resulting from changes in the number and location of bus stops.

### *Bus Stop Spacing, Transit Demand, and Service Reliability*

From the perspective of a transit agency, the ideal transit service is an efficient one with few stops characterized by high and predictable demand and few service reliability problems. Each passenger would like nothing more than for buses to arrive promptly at stops that are conveniently located (Koffman, 1990) such that access and egress times are minimized (Kittelson & Associates, 2003; Murray, 2001). Passengers prefer to minimize both their in-vehicle and out of vehicle times, with the latter being more highly valued by passengers (Kemp, 1973; Lago & Mayworm, 1981; Pushkarev & Zupan, 1977). Out of vehicle times are largely influenced by accessibility considerations as well as by service reliability issues which impact passenger wait times at stops (Abkowitz & Tozzi, 1987; Bowman & Turnquist, 1981; Turnquist, 1978, 1981). Service reliability problems also impact in-vehicle times in the form of increased bus running times (Koffman, 1990; Levinson, 1983; Saka, 2001; Wirasinghe & Ghoneim, 1981). These studies suggest that bus stop spacing, passenger demand, and service reliability are inherently linked.

Previous work related to bus stop spacing and location has focused on analysis of a single route or route-segment using datasets based on a limited number of observations, with the preferred methodological approache being mathematical models consisting of dynamic or linear programming (Chien, Qin, & Liu, 2003; Furth & Rahbee, 2000; Kuah & Perl, 1988; Murray & Wu, 2003; Saka, 2001; Wirasinghe & Ghoneim, 1981). The present analysis attempts to empirically analyze changes in demand due to bus stop consolidation and relocation based on an abundance of stop-level data using a pre-post study design.

Physical modifications to bus stop locations typically fall into one of the four typologies listed below:

1. Stop consolidation- the elimination of a stop from service
2. Stop relocation- the changing of a stop location
3. Stop consolidation and relocation- the elimination of one or more stops and relocation one of more adjacent stops
4. Stop addition- the addition of a new stop to a route

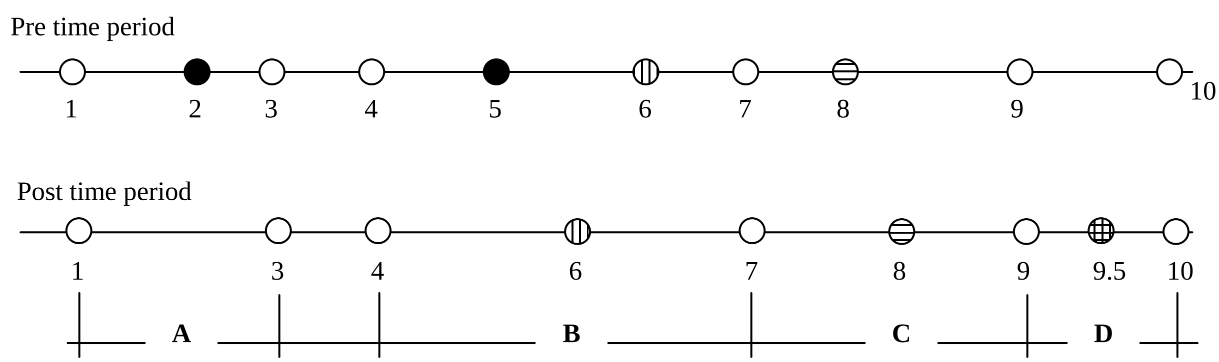


Figure 2: Type of Changes in Stop Spacing

In this study, a consolidation segment (CONS) is the unit of analysis. A consolidation segment (CONS) consists of a minimum of two or more bus stops. In the first case (A), the CONS consists of three stops in the pre time period (1, 2, and 3) and two stops in the post time period (1 and 3). In the second case (B), the CONS consists of four stops in the pre (4, 5, 6, and 7) and three in the post (4, 6, and 7). Cases C and D show stop relocation and stop addition, respectively.

Figure 3 shows a consolidation and relocation example and its effect on changes in parcel level accessibility. In this example, due to the consolidation of two stops into one, 19 parcels no longer have transit access within a quarter mile walking distance; three parcels now have access based on the stop relocation; while the level of relative accessibility has changed for 313 parcels due to modifications to the stop locations.

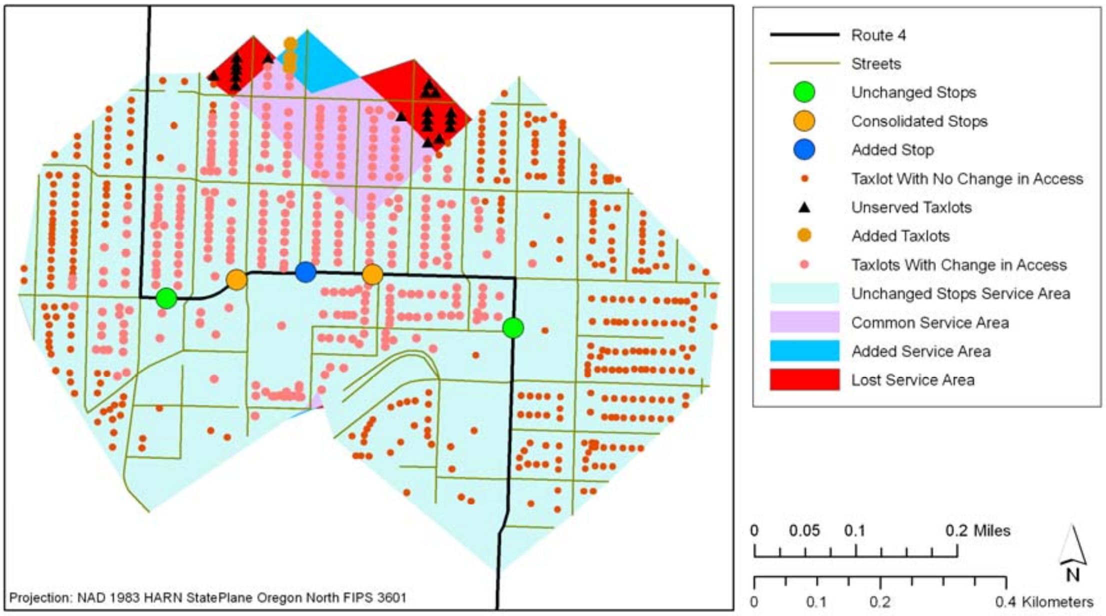


Figure 3: Effect of Consolidation and Relocation Parcel Accessibility

This example is important for several reasons. First, one can readily see that consolidation and relocation will have a negligible impact on patronage originating from peripheral areas, particularly in situations where there exists considerable overlap between adjacent bus stop service areas (e.g., in dense urban neighborhoods where bus stops are placed closely together). Second, for riders associated with a change in stop accessibility, many will have improved accessibility while others riders will be worse off. An important consideration relates to the notion of choice and captive riders. Given an adverse change in accessibility, a captive rider will likely keep using the service given few other transportation alternatives while choice riders may or may not keep using the service.

***Pre-Post Analysis of Bus Stop Consolidation and Relocation***

TriMet implemented the bus stop Streamline project in 1999. The primary goals of the project were to improve service reliability and reduce travel times while also improving the safety, accessibility and comfort of passengers on select routes in the system (Tri-County Metropolitan District of Oregon, 2002). One component of the project sought to remove redundant stops in order to save costs and improve bus running times. The methodology adopted by the agency consisted of defining multiple analysis segments along each route of interest, then analyzing each stop on a case by case basis for consolidation or relocation according to service standards for bus stop spacing and analysis of stop-level, archived automatic passenger counter information. The consolidation or relocation of stops involved an evaluation of various factors that influence demand at each stop including lift activity and average passenger demand. Although an improvement in bus running times was a stated goal of the Streamline project, little more than cursory attention was paid to the role of service reliability in relation to stop consolidation and relocation and their potential impacts on transit demand.

Two routes were selected for analysis- the 4 and 104. The routes represent separate ends of a radial through route traversing downtown Portland. These two routes had the highest number of implemented consolidations and relocations in the Streamline project. Figure 4 shows the segments where stop consolidation or consolidation and relocation occurred.

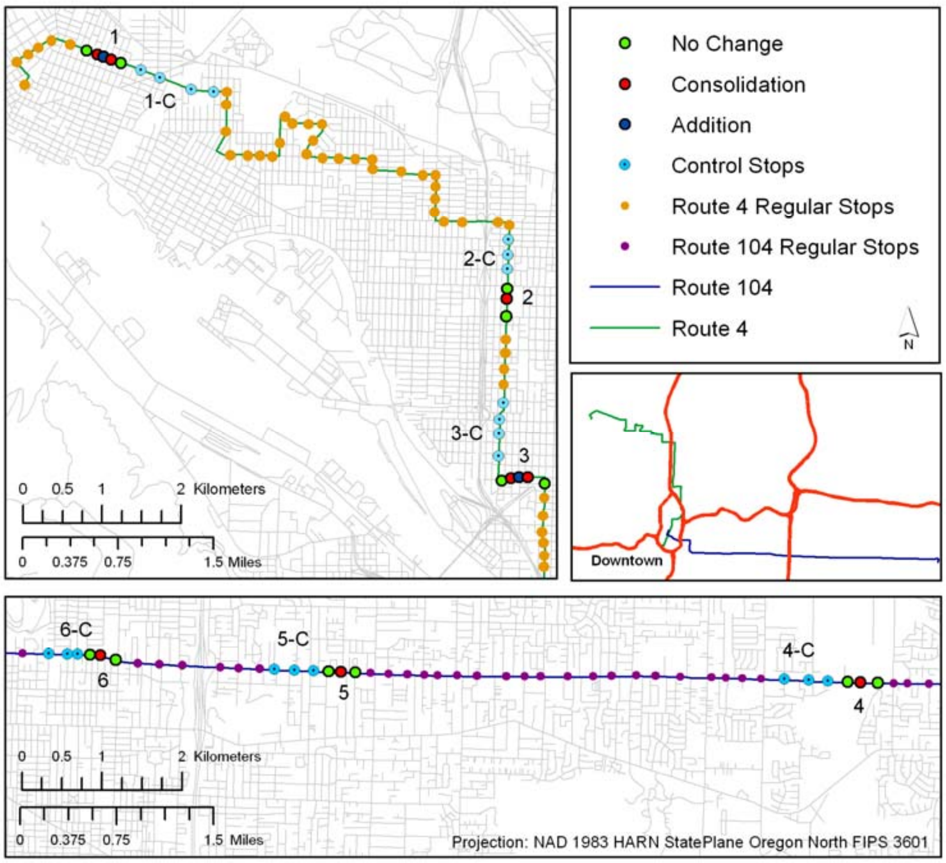


Figure 4: Study Area

Table 1 provides a summary of the changes that occurred along each CONS between the pre and post time periods.

Table 1: Description of Consolidation Segments

| Segment | Number of Stops Pre | Number of Stops Post | Type of Change | Route |
|---|---|---|---|---|
| 1 | 4 | 3 | Consolidation and Relocation | 4 |
| 2 | 3 | 2 | Consolidation | 4 |
| 3 | 4 | 3 | Consolidation and Relocation | 4 |
| 4 | 3 | 2 | Consolidation | 104 |
| 5 | 3 | 2 | Consolidation | 104 |
| 6 | 3 | 2 | Consolidation | 104 |

The study focuses on two types of consolidation 1) consolidation only and 2) consolidation and relocation. Six additional segments were added to the study for control purposes. These segments help to isolate the effects of consolidation from the effects of overall changes occurring at the route level. The consolidation control segments (CTRLS) are located adjacent to each CONS. No physical changes occurred on these segments between the two time periods. Each CTRLS contains the same number of stops as the adjacent CONS.

The analysis focuses on changes in demand during the morning peak (7:00 to 9:00 A.M.) since this time period is more closely associated with residential demand. Three months worth of weekday, stop-level passenger activity, service reliability, and operations data were obtained from TriMet 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. Since there is scant evidence in the literature on the long term effects of stop consolidation and relocation on transit demand, this study provides a unique opportunity for assessing changes in ridership resulting from changes to the number and location of bus stops.

The source data were aggregated to the trip-segment-level. Then the data was subjected to a cleaning process to check for outliers and missing information. These data were then summarized over all days on a per trip basis in order to generate the individual variables needed for the study. This produced 134 total CONS observations and 134 total CTRLS observations (67 in each time period for both CONS and CTRLS). Figure 5 shows the data reduction process from the original stop-level data aggregated to the trip-segment.

| | Stop | | Trip-Segment | | Cleaned Trip-Segment | | Match Aggregated Trip-Segment | |
|---|---|---|---|---|---|---|---|---|
| | CONS | CTRLS | CONS | CTRLS | CONS | CTRLS | CONS | CTRLS |
| Pre | 14078 | 14685 | 4197 | 4235 | 3945 | 3915 | **67** | **67** |
| Post | 9720 | 11786 | 3529 | 3571 | 3313 | 3285 | **67** | **67** |
| Total | 50269 | | 15532 | | 14458 | | **268** | |

Figure 5: Data Reduction

Differences in means tests for paired samples were used to determine whether any statistically significant differences exist between the various demand, service quality, and bus operations variables between the pre and post time periods (post-pre), with the consolidation and the control segments considered separately. An additional paired differences test was used to see if important changes occurred between the differences in the consolidation and the control segments (CONS-CTRLS). Figure 6 is a diagram showing how the tests were performed for each variable.

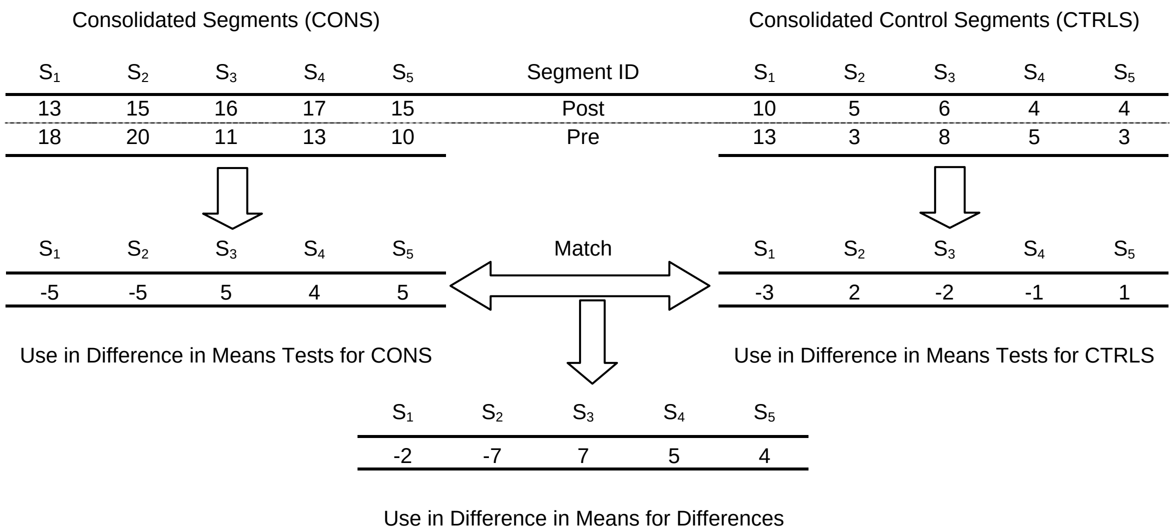


Figure 6 Paired Differences Tests

Table 2 shows the results of the differences in means tests. The midpoints of the ranges, rather than the actual ranges themselves were used in the statistical tests. A paired sample t-test indicates that there is no statistically significant change in the difference in mean passenger boardings between the CONS and CTRLS samples.

Table 2: Paired Differences Tests

| | Mean Difference | | C.V. Difference | | Difference of Difference | |
|---|---|---|---|---|---|---|
| | CONS | CTRLS | CONS | CTRLS | Mean | C.V. |
| Boardings | 0.220 | 0.121 | -0.009 | -0.056 | 0.044 | 0.047 |
| Alightings | 0.080 | -0.108* | -0.522* | 0.345 | -0.879* | 0.218* |
| Boardings + Alightings | 0.299 | 0.014 | -0.045 | 0.010 | -0.061 | 0.265 |
| Dwell Time | 1.075 | -0.146 | 0.072 | -0.017 | 0.082 | 0.876 |
| Lift Usage | 0.004* | 0.002* | 0.435 | 0.462* | 0.066 | 0.002 |
| Unscheduled Stops | 0.074 | -0.043 | 0.127 | 0.131 | -0.011 | 0.074 |
| Actual Stops | -0.784* | -0.041 | 0.076* | -0.003 | 0.073* | -0.800* |
| Departure Delay @ Origin | -2.295 | 1.650 | 1.689* | 2.071 | 0.062 | -3.204 |
| Departure Delay @ Destination | -1.700 | 2.859 | -3.832* | 0.830 | -4.836* | -4.556 |
| Run Time | 0.595 | 1.208 | -4.843 | -1.399 | -3.608 | -1.353 |

* Indicates statistical significance at 95% level of confidence

The difference in the average number of per trip boardings in a CONS increased by 0.22 passengers following stop consolidation and relocation. This finding is encouraging given that adjustments in both the number and locations of bus stops could potentially result in a loss of ridership. In the present analysis, a total of 6 stops were eliminated and 2 were relocated across all of the CONS with no apparent reduction in ridership. The difference in the mean number of per trip boardings in the CTRLS increased by 0.12 relative to the baseline period. The last column comparing the difference of the differences between the consolidation and control segments is included for control purposes. Since this test is not significant with respect to differences between the CONS and CTRLS it indicates that one can readily compare the CONS and CTRLS results with respect to differences in mean boardings. Thus, one is assured that there is no statistically significant difference between the differences in means boardings between the CONS and the CTRLS.

While the difference in mean boardings in the CONS is the primary variable of interest, other confounding factors may exist that could potentially explain changes in demand between the pre and post time periods. A number of additional transit service reliability and operating condition variables are presented in Table 2 in order to better understand changes that occurred along the route between the two study periods. Since a number of these variables show changes occurring over time and between the consolidation and control segments, a multivariate model that can yield additional information is needed. In particular, it is worth discovering the factors that may be responsible for the measured increase in demand following consolidation and relocation.

***Demand Model***

A multivariate model was developed to analyze the consequences of consolidation on demand at the trip-segment-level. Theory suggests that demand is a function of service supply, population or employment density, access to stops, socio-demographic characteristic, and transit service reliability. Since the data used in the present analysis are summarized by trip, supply is given and therefore not modeled. Summary statistics for the variables used in the model are presented in Table 4.

Table 4: Summary Statistics

| Var. | Description | Mean | SD | Min. | Max. |
|---|---|---|---|---|---|
| ONS | Boardings (mean) | 2.52 | 1.88 | 0 | 9.49 |
| CONSPRE | Consolidation segment in pre time period (1 = true) | 0.25 | 0.43 | 0 | 1 |
| CONSPOST | Consolidation segment in post time period (1 = true) | 0.25 | 0.43 | 0 | 1 |
| CTRLSPOST | Consolidation control segment in post time period (1 = true) | 0.25 | 0.43 | 0 | 1 |
| POP | Population (1000s) | 26.68 | 16.60 | 2.97 | 70.53 |
| INC | Income (1000s) | 36.20 | 4.98 | 24.52 | 43.54 |
| DDCVO | Departure Delay C.V. at Origin | 1.15 | 0.98 | 0.16 | 9.84 |
| RTCV | Run Time C.V. | 0.31 | 0.11 | 0.12 | 1.05 |
| AAD | Average Access Distance (miles) | 0.30 | 0.07 | 0.22 | 0.55 |
| USS | Unscheduled Stops (actual) | 0.46 | 0.38 | 0 | 2 |

Three consolidation and control dummy variables are included to capture the effects of changes that occurred across the analysis segments between the two time periods, with CTRLSPRE being the reference case. Several control variables are included in the model for the purpose of isolating effects of consolidation from other explanatory factors. POP refers to the number of people living within the segment service area defined by one-quarter mile network distance from the relevant stops in each segment. INC is median household income assigned to the service area. Differences in service reliability are addressed through use of 1) the coefficient of variation of run time (RTCV) and 2) the coefficient of variation of departure delay at the origin stop (DDCVO). The first variable captures the effect of delay to in-vehicle passengers while the second variable is related to passenger wait times at stops. The model also includes a control variable to address changes in average stop access (AAD). AAD is calculated based on the average access distance on the network from all parcels within the service area to all bus stops. Finally, a variable is added to control for the number of unscheduled stops (USS) since reductions in the number of physical stops may lead to an increase in the number of unscheduled stops. Table 5 shows the results of the ordinary least square regression model.

Table 5: Demand Model

| Var. | Coefficient | T-Ratio |
|---|---|---|
| CONSPRE | -0.381* | -1.758 |
| CONSPOST | 0.256 | 1.189 |
| CTRLSPOST | 0.266 | 1.334 |
| POP | 0.033* | 6.073 |
| INC | -0.010 | -0.541 |
| DDCVO | -0.300* | -3.756 |
| RTCV | -1.728* | -2.613 |
| AAD | -0.076 | -0.075 |
| USS | 2.506* | 10.980 |
| Constant | 1.720* | 2.311 |
| R2 = 0.56 | | |
| N = 268 | | |

* Indicates statistical significance at the 90% level of confidence

From Table 2 it was shown that there was a change in demand for both the consolidation segments and the control segments but it was not clear what the contributing factors were. The regression analysis shows a statistically significant difference in demand in the pre consolidation segments relative the pre control segments with a negative sign. Demand pre consolidation along consolidation segments was lower than demand among control segments. Since the post consolidation segments and the post control segments did not have a statistically significant effect on mean boardings compared to the pre time period control segment, one can be reasonably confident that the service reliability improvements that were shown in Table 2 are positively related to the increase in mean boardings following consolidation. Both reliability measures are shown to be statistically significant in the regression model with a higher magnitude for run time variability.

Figure 7 shows the predicted average boardings profile for both samples. The figure shows that average boardings per trip per segment have increased by 40% in the consolidation segment when comparing the pre time period to the post while the increase in the mean number of boardings in the control sample was 3%. This substantial increase in boardings differs from theory which suggests that the consolidation segments should lose ridership if all other variables were held constant. As expected, unscheduled stops are associated with an increase in demand.

All of these changes were accompanied by a statistically significant decrease in average departure delay at the origins.

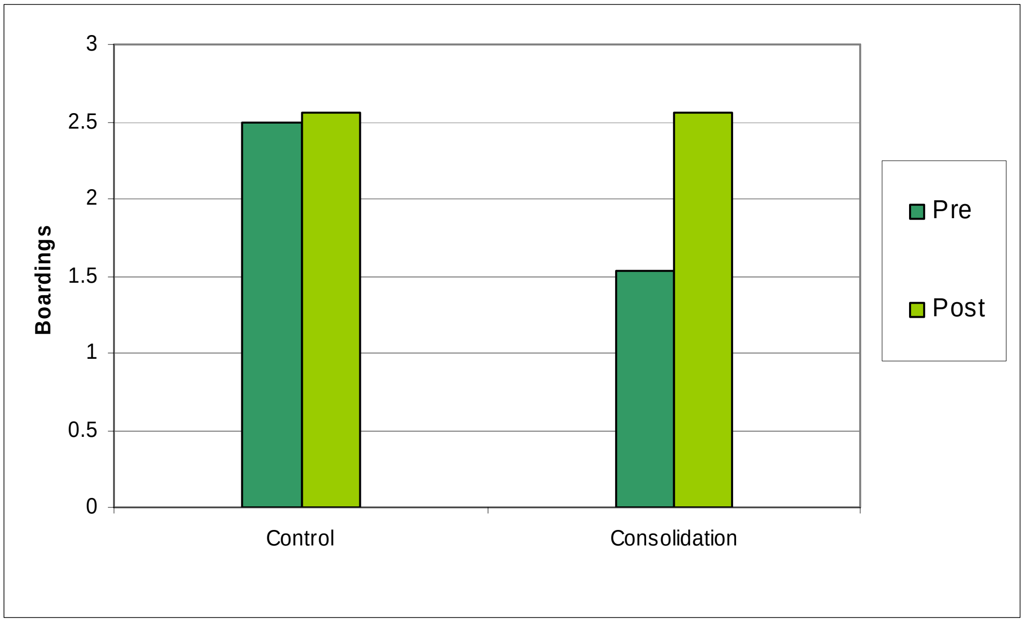


Figure 7: Predicted Boardings Profile for Sample Type in Relation to Average Boardings

This finding agrees with theory that transit agencies will lose ridership if service becomes highly variable. Increase in average access shows a minor impact on demand. This can be partially explained by the existence of overlapping service areas and type of passengers living service area.

### *Conclusion*

We empirically analyzed the effects of bus stop consolidation from both the perspective of the transit operators as well as passengers. The study makes extensive use of archived operations and passenger activity data recorded at the bus stop level. The study included a statistical analysis of the difference in mean boardings between the two samples to compare with changes in service. Generally speaking, we find that the impact of stop consolidation on passenger demand is negligible. The regression model showed that the lack of adverse consequences can be attributed to positive changes in service reliability that accompanied consolidation. The approach used in the paper can help other researchers measure the effects of changes in bus transit service characteristics on passenger demand.

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