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Research Note: Determinants of Bus Dwell Time

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Abstract

This research note reports an analysis of dwell times at bus stops using archived Automatic Vehicle Location/ Automatic Passenger Counter (AVL/APC) data reported at the level of the individual bus stop. The data provide a large number of observations that serve to better understand the determinants of dwells, including analysis of rare events, such as lift operations. The analysis of bus dwell times at bus stops is applicable to TriMet, the transit provider for the Portland metropolitan area, and transit agencies in general. The determinants of dwell time include passenger activity, lift operations and other effects: low floor bus, time of day and route type.

Introduction

This research note reports on analysis of dwell times at bus stops using archived Automatic Vehicle Location/ Automatic Passenger Counter (AVL/APC) data reported at the level of the individual bus stop. The archived AVL/APC data provides a rich set of dwell time observations to better understand the determinants of dwells. In addition, the large quantity of data allows analysis of rare events, such as lift operations. The analysis of bus dwell times at bus stops was originally used to estimate delay associated with bus lift use operations for passengers with disabilities for the Tri-County Metropolitan Transportation District of Oregon (TriMet), the transit provider for the Portland metropolitan area. In addition, the analysis yielded useful information about dwell times that has applicability to transit agencies in general. (Dueker, et al. 2001)

The literature on bus dwell times is sparse due to the cost and time required for manual data collection. Consequently, most prior analyses tended to be quite route-specific or focused on analyzing various issues causing bus delay, and are based on small samples. Previous studies on dwell time have used ordinary least squares (OLS) regression to relate dwell time to boardings and alightings, with separate equations estimated for different operating characteristics likely to affect dwell time. Levinson's (1983) landmark study of transit travel time performance reported that dwell time is equal to 5 seconds plus 2.75 seconds time the number of passengers boarding or alighting. Guenthner and Sinha (1983) found a 10-20 second penalty for each stop plus a 3-5 second penalty for each passenger boarding or alighting. However, the dwell time models, based on small samples, have low explanatory power when controlling other factors, such as lift, fare structure, number of doors. Guenthner and Hamet (1988) looked at the relationship between dwell time and fare structure, controlling for the amount of passenger activity. Lin and Wilson (1992) found dwell time effects vary depending on mode and service type with the greatest effect on long, high frequency, high ridership bus lines. Bertini and El-Geneidy (forthcoming) modeled dwell time for a single inbound radial route in the morning peak period in their analysis of running time at the individual trip level. They incorporated the results of the dwell time analysis directly into the trip time model by estimating parameters for number of dwells and number of boarding and alighting passengers.

Archived Data

TCRP Project H-28, Uses of Archived AVL/APC Data to Improve Transit Performance and Management, identifies the bus stop as the appropriate spatial and temporal level for data aggregation and integration. This integration of scheduled and actual arrival time at the bus stop location is crucial for research on operations and control strategies. Integrating data at the bus stop level supports applications such as AVL, automated stop annunciation, and next-stop arrival time information. Importantly, if these bus stop data are archived on-time performance and bus bunching analysis can also be supported. (Furth, et al 2003)

TriMet operates 97 bus routes, 38 miles of light rail transit, and 5 miles of street car service within the tri-county Portland metropolitan region. TriMet's bus lines carry approximately 200,000 trips per day, serving a total population of 1.3 million persons within an area of 1,530 square kilometers (590 square miles).

TriMet implemented an automated Bus Dispatch System (BDS) in 1997 as a part of an overall operation and monitoring control system upgrade.

The main components of the BDS include:

1. AVL based upon differential global positioning system (GPS) technology, supplemented by dead reckoning sensors;
2. Voice and data communication system using radio and cellular digital packet data (CDPD) networks;
3. On-board computer and control head displaying schedule adherence information to operators, detection and reporting of schedule and route adherence to dispatchers;
4. APCs on front and rear doors of 70% of vehicles in the bus fleet; and
5. Computer-aided dispatch (CAD) center.

The BDS reports detailed operating information in real time by polling bus location every 90 seconds, which facilitates a variety of control actions by dispatchers and field supervisors. In addition, the BDS archives detailed stop-level data from the bus during all trips that are post-processed. Unique among U.S. transit systems, the TriMet BDS archives the data related to bus operations for every bus in the system each day. This includes the actual stop time (compared to scheduled time), dwell time, and the number of boarding and alighting passengers. The BDS also logs data for every stop in the system, whether or not the bus stops to serve passengers. This archived data forms a rich resource for planning and operational analysis as well as research.

Each TriMet bus stop is geo-coded as a predefined 30-meter (98 foot) stop circle. An arrival time is recorded when a bus enters the stop circle, and a departure time is recorded when the bus departs the stop circle. The arrival time and the departure time are recorded at all stops even if the bus doesn't stop to serve passengers. If the door opens to serve passengers, a dwell is recorded, and the arrival time is overwritten by the time when the door opens. Dwell time (in seconds) is recorded as the total time that the door remains open.

When passenger activity occurs, the APCs count the total number of boardings and alightings. The APCs are installed at both front and rear doors, and the infrared beams detect passenger movements. The APCs are only activated if the door opens. The use of a lift for assisting passengers with disabilities is also recorded in the BDS database.

The archived AVL/APC data have been used in various studies of operations control and service reliability (Strathman, et al. 1999; Strathman et al 2000; Strathman et al 2001a; Strathman et al2001b), for route-level passenger demand modeling (Kimpel, 2001), for models of trip and dwell time (Bertini and El-Geneidy, forthcoming), and for evaluating schedule efficiency and operator performance (Strathman et al 2002).

Data

The data are from a two-week time period in September 2001, for all of TriMet's regular service bus routes. For this analysis, dwell time (DWELL) is the duration in seconds the front door is open at a bus stop where passenger activity occurs. The data were purged of observations associated with the beginning and ending points of routes, layover points, and unusually long dwell time (greater than five minutes (300 seconds))[1]. Observations with passenger loads (LOAD) of over 70 persons were also excluded, indicating the automatic passenger counter data were suspect. Two weeks of data generated nearly 400,000 dwell observations. Even though lift operations occur at less than one percent (0.7 %) of dwells, the number of lift operations is large enough for a robust estimation (N = 2,603).

Table 1 presents the descriptive statistics for data used in the statistical analysis of the effect of bus lifts on dwell times at bus stops. Table 1 shows the effect of a lift operation on dwell time. Dwell times associated with a lift operation have higher variances than those without, which is a reason to estimate separate models later in the analysis.

Insert Table 1 here

Table 2 presents the descriptive statistics for variables used in the full-sample dwell time model. The data show a mean dwell time of 12.5 seconds with 1.22 boardings and 1.27

alightings per dwell. Also, 59% of the dwells involved low floor buses. Dwells by time of day (TOD) are 15% in morning peak period (6-9 AM), 41% in mid-day (9 AM -3 PM), 17% in afternoon peak period (3-6 PM), 20% in evening (6-10 PM), and 7% in late night and early morning (10 PM- 6 AM). The mix of dwells by route type are: 69% radial route, 6% feeder route and 25% cross-town route. Also, the average dwell occurs 2.35 seconds behind schedule.

Insert Table 2 here

Dwell Time Estimation

Table 3 presents the results of the full-sample model (both with and without lift operation). Dwell time is explained by boarding passengers (ONS), alighting passengers (OFFS), whether the bus is ahead or behind schedule (DELAY), whether the lift is operated (LIFT), whether the bus is a low floor bus (LOW), passenger friction (ONOFFLD2)[2], time of day, and type of route. The estimation results indicate that each boarding passenger adds 3.75 seconds to dwell time and each alighting passenger adds 1.90 seconds. Square terms of passenger activity are used to account for diminishing marginal effects of additional boarding and alighting passengers on dwell time. Each additional boarding passenger is estimated to take 0.04 seconds less, while each additional alighting passenger takes 0.03 seconds less. The negative coefficient on DELAY indicates that dwell times tend to be less for late buses than for early buses[3]. The CONSTANT value of 5.17 seconds reflects the basic opening and closing door process, and passenger activity, time of day, route type, and lift operation, adds to that time by the values of the coefficients.

These other variables have small but significant effects. Time-of-day estimates are referenced to the morning peak period (TOD1). Mid-day dwells (TOD2) are 1.39 seconds longer than morning peak dwells, afternoon peak dwells (TOD3) are 0.93 seconds longer than morning peak dwells, evening period dwells (TOD4) are 1.24 seconds longer than morning peak dwells, and late evening and early morning period dwells (TOD5) are not significantly different than morning peak dwells. The morning peak period is the most efficient in terms of serving passengers, perhaps due to regular riders and more directional traffic. Regular rider may tend to board using bus passes[4] and ask fewer questions. The more directional traffic would reduce the mixing of boardings and alightings at the same stop.

The type of route (radial (RAD), feeder (FEED), and cross town (CTOWN)) also affects dwell times. Feeder routes have 0.56 second longer dwells than radials, the reference route type, and cross town routes have 0.41 second shorter dwells than do buses operating on radial routes.

Insert Table 3 here

Lift Operation Effects

The estimated effect of a lift operation on dwell time in the full-sample model is 67.80 seconds. A Chow test was used to determine a separate model is needed for dwells where lift operation occurs. This lift operation effect is examined more closely in a separate model of dwell times involving lift operations only.

Table 4 presents the descriptive statistics and Table 5 presents the results of the bus dwell time model for lift operation-only dwells. The mean dwell time lift operation-only dwells is 87.93 seconds, and is explained by the same variables as the overall dwell time model. It is interesting to examine the coefficients. For example a low-floor bus reduces the dwell time for lift operations by nearly 8 seconds. But the large CONSTANT value of 75.39 seconds indicates that the majority of time is for the lift operation itself.

Insert Table 4 here

Insert Table 5 here

An estimate of delay associated with lift operation can be used to modify an estimate of arrival time provided to transit users at downstream stops. However, we have three choices of delay time estimates for lift operation. One is the 67.80 seconds, the coefficient on LIFT from the model of all dwell times. Another is the difference between the mean of all dwell time with lift operations (87.93 seconds) and without lift operations (11.57 seconds). This difference is 76.36 seconds. The third choice is the effect of a lift operation on running time from an earlier study of route running times (Strathman et al. 2001a). This third choice provides an estimate of the lift effect as 59.80 seconds. This smaller value indicates that operators make up some of the time lost due to lift operations before the end of their trip.

We recommend the middle estimate of 67.80 seconds (the coefficient on the LIFT dummy variable from the all-dwells estimation) be selected as the delay estimate at the outset of the lift event and that it be updated with the actual dwell time less the mean dwell time without lift operation as the bus departs that stop. In this manner, next stop bus arrival time estimates could be refined when impacted by delays associated with lift operations. This would require a message from the bus to the Bus Dispatch Center at the onset of the lift operation and another at the conclusion.

Low Floor Bus Effect

TriMet was also interested in the effect of low floor buses on dwells, particularly dwells with lift operations. In the all-dwell model, the estimated effect of a low-floor bus is a 0.21 seconds (1.67%) reduction in dwell time. A typical TriMet route has 60 bus stops. On average a single bus trip stops at 60% of them. Thus, the 0.21 second reduction in dwell time for a low floor bus translates into a 7.56 second per trip saving in total running time.

The estimated effect of a lift operation in the full-sample model is 67.80 seconds. The lift operation effect is also examined more closely in a model of dwell times involving lift operations only. The mean dwell time for stops where the lift is operated of 87.93 seconds is explained by the same variables as the overall dwell time model. A low-floor bus reduces dwell time for lift operations by nearly 8 seconds (9.0%). Consequently, this model shows the impact of low floor buses on dwell time, which can be expanded into savings at system level.

Conclusion

The original purpose of this research was to identify the effects of delay that occur at unexpected times, such excess dwell time resulting from bus-lift operations. Our research provides an estimate of delay at the time of initiation of the occurrence, which needs to be updated with the actual time of delay at the ending time of the occurrence. This research provides a basis for shifting from predicting transit bus arrival times for customers based on normal operating conditions to one that predicts transit vehicle arrival time when operating conditions are not normal. (Dueker, et al. 2001)

An ancillary benefit of this research identified the general determinants of bus dwell time. As expected, passenger activity is an important determinant. In addition, the archived AVL/APC data provided a large sample size that allowed examination of determinants, such as low floor buses, time of day, and route type effects, and a separate model for dwells with lift operation only.

Footnotes

1. Long dwells are likely to be associated with vehicle holding actions or operator shift changes, and thus should be excluded from the analysis.
2. A passenger friction factor was constructed to account for passenger activity on buses that are near or fully loaded. It was posited that heavily loaded buses have greater dwell times. A proxy variable was constructed by interacting ONS, OFFS, and LOAD greater than or equal to 30 passengers. However, this variable did not perform as expected. The negative coefficient is counterintuitive. Nor do other forms of this concept perform as expected, LOAD alone or LOAD greater than 30 in conjunction with ONS or OFFS. The negative coefficient may be due to operators who hurry dwells when buses are full to maintain schedules. Another possible explanation is that dwell times are minimal on fully loaded buses because alightings become the predominate passenger activity. Our analysis shows that alightings take considerably less time than boardings. Furthermore, on fully loaded buses, it is not likely that there will be a significant amount of passenger activity at any one stop.
3. Operators tend to hurry to regain schedule adherence.
4. The farebox is not integrated with the BDS, so we do not know the proportion of cash paying boarding passengers at the stop level.

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List of Tables

Table 1: Bus Dwell Time: Descriptive Statistics

DWELL	MEAN TIME	ST. DEV.	N
With lift operation	87.93	47.38	2,603
Without lift operation	11.57	10.56	366,185
Both	12.60	16.01	369,870

Time in seconds

Table 2: Bus Dwell Time Model, Full Sample: Descriptive Statistics

NAME	MEAN	ST. DEV.	VAR.	MIN.	MAX.
DWELL	12.50	16.01	256.36	2.00	300.00
ONS	1.22	1.99	3.94	0.00	45.00
ONS2	5.42	26.49	701.46	0.00	2,025.00
OFFS	1.27	1.90	3.60	0.00	47.00
OFFS2	5.21	25.14	631.94	0.00	2,209.00
DELAY	2.35	3.55	12.58	-29.66	57.50
LIFT	0.01	0.08	0.01	0.00	1.00
LOW	0.59	0.49	0.24	0.00	1.00
ONOFFLD2	0.12	0.33	0.11	0.00	1.00
TOD1	0.15	0.36	0.13	0.00	1.00
TOD2	0.41	0.49	0.24	0.00	1.00
TOD3	0.17	0.37	0.14	0.00	1.00
TOD4	0.20	0.40	0.16	0.00	1.00
TOD5	0.07	0.25	0.06	0.00	1.00
RAD	0.69	0.46	0.22	0.00	1.00
FEED	0.06	0.23	0.05	0.00	1.00
CTOWN	0.25	0.43	0.19	0.00	1.00
N	369,870				

Table 3: Bus Dwell Time Model, Full Sample: Results

NAME	COEF.	STD. ERR.	T-RATIO
ONS	3.75	0.02	214.60
ONS2	-0.04	0.00	-27.10
OFFS	1.90	0.02	106.10
OFFS2	-0.03	0.00	-24.30
DELAY	-0.14	0.01	-22.48
LIFT	67.80	0.25	271.60
LOW	-0.21	0.04	-4.85
ONOFFLD2	-0.94	0.07	-14.24
TOD2	1.39	0.06	22.06
TOD3	0.93	0.08	12.45
TOD4	1.23	0.07	17.19
TOD5	-0.04	0.10	-0.43
FEED	0.58	0.09	6.19
CTOWN	-0.41	0.05	-8.30
CONSTANT	5.17	0.07	78.49
R2 ADJ.	0.38		

Table 4: Bus Dwell time Model, Lift Operations Only: Descriptive Statistics

NAME	MEAN	ST. DEV.	VAR.	MIN.	MAX.
DWELL	87.93	47.38	2,244.40	2.00	298.00
ONS	2.90	3.92	15.34	0.00	45.00
ONS2	23.75	75.89	5,759.40	0.00	2,025.00
OFFS	2.73	3.50	12.28	0.00	47.00
OFFS2	19.72	66.10	4,368.50	0.00	2,209.00
DELAY	3.08	3.87	14.96	-6.71	24.63
LOW	0.56	0.50	0.25	0.00	1.00
ONOFFLD2	0.15	0.36	0.13	0.00	1.00
TOD1	0.08	0.26	0.07	0.00	1.00
TOD2	0.56	0.50	0.25	0.00	1.00
TOD3	0.18	0.39	0.15	0.00	1.00
TOD4	0.15	0.36	0.13	0.00	1.00
TOD5	0.03	0.17	0.03	0.00	1.00
RAD	0.66	0.47	0.23	0.00	1.00
FEED	0.06	0.24	0.06	0.00	1.00
CTOWN	0.28	0.45	0.20	0.00	1.00
N	2,603				

Table 5: Bus Dwell Time Model, Lift Operations: Results

NAME	COEF.	STD. ERR.	T-RATIO
ONS	9.11	0.40	22.75
ONS2	-0.17	0.02	-8.56
OFFS	0.42	0.41	1.04
OFFS2	-0.04	0.02	-1.70
DELAY	-0.25	0.21	-1.17
LOW	-7.95	1.65	-4.83
ONOFFLD2	-4.58	2.33	-1.97
TOD2	-3.89	3.05	-1.27
TOD3	-4.50	3.43	-1.31
TOD4	-5.16	3.51	-1.47
TOD5	-13.08	5.50	-2.38
FEED	11.23	3.35	3.35
CTOWN	-3.43	1.79	-1.91
CONST.	75.39	3.21	23.47
R2 ADJ.	0.29		

[1] Long dwells are likely to be associated with vehicle holding actions or operator shift changes, and thus should be excluded from the analysis.

[2] A passenger friction factor was constructed to account for passenger activity on buses that are near or fully loaded. It was posited that heavily loaded buses have greater dwell times. A proxy variable was constructed by interacting ONS, OFFS, and LOAD greater than or equal to 30 passengers. However, this variable did not perform as expected. The negative coefficient is counterintuitive. Nor do other forms of this concept perform as expected, LOAD alone or LOAD greater than 30 in conjunction with ONS or OFFS. The negative coefficient may be due to operators who hurry dwells when buses are full to maintain

schedules. Another possible explanation is that dwell times are minimal on fully loaded buses because alightings become the predominate passenger activity. Our analysis shows that alightings take considerably less time than boardings. Furthermore, on fully loaded buses, it is not likely that there will be a significant amount of passenger activity at any one stop.

[3] Operators tend to hurry to regain schedule adherence.

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