



Examining the association between bus transit reliability and the number of boarding passengers

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Abstract

The focus of this study is to examine the association between bus transit reliability and the number of boarding passengers at bus-stop level using data obtained from the Charlotte Area Transit System (CATS) in the city of Charlotte, North Carolina, USA for the year 2017. The on-time performance percentage was computed and used as bus transit reliability at bus-stop level. Two different thresholds were considered to compute the on-time performance measure. The ridership data was processed to compute the average number of boarding passengers per bus at bus-stop level. The findings indicate that the day of the week, time of the day, direction of travel, and the type of bus-stop influence the association between the on-time performance percentage and the average number of boarding passengers per bus.

Keywords Bus · Reliability · On-time · Boarding passengers · Bus-stop

1 Introduction

Growing population, rapid urbanization, and increase in travel demand emphasize the need for public transportation systems and sustainable transportation planning. The public transportation industry in the United States is worth \$80 billion (Litman

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2016). In 2019 alone, 9.9 billion trips were made using public transportation systems, and they approximately account for 34 million trips each weekday (Hughes-Cromwick 2019).

Many towns and cities need reliable public transportation systems to improve mobility and mode choices for captive and choice-based riders. Bus, bus rapid transit (BRT), light rail transit (LRT), commuter rail, etc. are typical public transportation systems across the United States. Several strategies are being implemented to improve these public transportation systems, including park-and-ride services, intermodal services, segregated right-of-way, stations involving platforms with high-quality amenities, and usage of intelligent transportation systems-based applications (Ishaq and Cats 2020; Devi et al. 2021). Despite the greater demand for public transportation and improvement in related services, ridership has not increased significantly in the last two decades (Mallett 2018).

There could be a number of reasons for the insignificant increase, no change or decrease in ridership. These include increasing private car ownership, relatively low gas prices, urban sprawl and trip lengths, transit service laybacks, and the rise of taxi/ride services (for example, Uber and Lyft) (Graehler et al. 2019). Bus transit reliability is an important service characteristic from a bus rider perspective. The inconvenience, uncertainty in the operations, and added time of unreliable services further diminish the public transportation rider confidence and may ultimately result in the overall decline of ridership. In other words, providing reliable bus service might foster a more significant, more satisfied, and committed base of bus riders. This study explores this hypothesis.

The perception of public transportation reliability among riders is based on on-time arrival/departure and waiting time (Strathman and Hopper 1993; Nakanishi 1997; Strathman et al. 1999; Bertini and El-Geneidy 2003; Surprenant-Legault and El-Geneidy 2011; Currie and Delbosc 2011; Kathuria et al. 2020). Intra-city bus services often show inconsistencies in on-time arrival/departure at bus-stops. This could be because buses typically share their travel space with other transportation modes, making them vulnerable to recurrent and non-recurrent congestion.

The ridership and traffic conditions vary with the day of the week, time of the day, direction of travel, and type of bus-stop. For example, traffic volume is typically higher on weekdays and peak hours when compared to weekends and off-peak hours. The number of riders traveling toward the central business district (or downtown/uptown) is typically higher in the morning peak hour while the number of riders traveling away from the central business district (or downtown/uptown) is typically higher in the evening peak hour. The regular traffic flows typically follow the same directional trend. The travel times (for buses as well as regular traffic) and dwell times at bus-stops also depend on the direction of travel and time of the day. The spatial location of the bus-stop (in an urban or suburban area; start, middle or end of a route) and the type of bus-stop (for example, transfer point) are other associated factors. This study, therefore, aims to examine the association between bus transit reliability (expressed as on-time performance percentage) and ridership (expressed as the average number of boarding passengers per bus) at bus-stop level by day of the week, time of the day, direction of travel, and type of bus-stop. The

findings provide vital insights for public transportation agencies to enhance service and maximize benefits from related investments.

2 Literature review

Researchers and practitioners in the past focused on investigating the effect of factors like population density, housing around transit stops, accessibility to stops, and advanced traveler information on public transportation systems (Cervero 1994; Pulugurtha et al. 1999, 2011; Abdel-Aty 2001; Chakrabarti 2017). The provision of new and reliable public transportation systems is likely to relieve congestion and increase ridership as reliability plays a vital role in choosing public transportation as a travel mode.

Explanatory models were developed using population characteristics, regional economy, geographic characteristics, and transportation variables in the past. The factors affecting public transportation ridership that were considered in the past include transit fare, bus-stop amenities, and transit service quality (Syed and Khan 2000; Tirachini et al. 2010; Lai and Chen 2011; Sharaby and Shiftan 2012; Redman et al. 2013; Abenoza et al. 2017). External factors like road characteristics, built environment, land use characteristics, socioeconomic characteristics, and demographic characteristics at a stop, along a route or in the network also influence public transportation ridership (Pulugurtha and Agurla 2012; Guerra 2014; Bhattacharjee and Goetz 2016). Factors such as pedestrian-friendly intersections, walk and bike connectivity, value of riders' travel time and savings, and safety at public transportation stops influence ridership (Khattak and Rodriguez 2005; Kim et al. 2007; Forsyth et al. 2009; Choi et al. 2012; Chepuri et al. 2020; Pulugurtha and Srirangam 2022). The findings from past research also indicate that safety and accessibility to bus transit systems play a vital role in increasing the use of such systems, i.e., ridership (Pulugurtha et al. 1999, 2011; Pulugurtha and Vanapalli 2008). It is also important to integrate the perspectives of public transportation system riders and agencies on reliability as well as consider the response of public transportation system riders to schedule adjustments when developing plans to improve reliability (Diab et al. 2015).

The number of boarding and alighting passengers or crowding could influence the reliability of a public transportation system. Paudel (2021) analyzed the effect of ridership on the reliability of a public bus service. In their study, ridership is the number of people inside the bus while reliability is the difference between a scheduled arrival time and an actual arrival time. A difference of zero between a scheduled arrival time and an actual arrival time is considered as reliable. Their findings suggest that an additional unit increase in the number of passengers (crowding) results in a 0.9% reduction in the reliability of bus services. In other words, higher volumes of bus ridership (more crowded buses) cause a significant increase in the variance of bus transit reliability. Other studies related to the effect of crowding include the valuation of sitting and standing in metro trains (Tirachini et al. 2016) and cost estimation with large-scale smart card and vehicle location data (Hörcher et al. 2017).

While many studies in the past focused on ridership and related factors, a relatively low number of studies in the past focused on the reliability of public transportation systems. Ge et al. (2022) synthesized literature on robustness and disturbances in public transportation systems. They suggested a connected and intertwined approach to manage disturbances, disruptions, and delays to enhance robustness and reliability of public transportation systems. Soza-Parra et al. (2022) studied the effect of travel time reliability on mode choice for bus and metro service in Santiago, Chile. They found that travel time reliability has a relevant impact on travelers' decisions, particularly for bus service as it shows a higher deviation in travel time reliability than the metro system.

Computing performance measures like reliability of public transportation systems has improved since advanced monitoring and tracking systems have been deployed in the recent years (Chepuri et al. 2018). The reliability-based performance measures provide vital insights for improving ridership and help public transportation agencies assess specific goals identified to improve services. The measures such as the punctuality index based on routes, the deviation index based on stops, and the evenness index based on stops (Chen et al. 2009), the frequency of service (Brakewood et al. 2015), mixed traffic lanes, bus lanes, median bus-ways on city streets, reserved lanes on freeways (Levinson 2004), the number of stations, the average distance between two stations, average speed, average peak/non-peak headways, and vehicle capacities influencing public transportation system performance were considered as some of the measures influencing ridership. Likewise, the on-time performance percentage (OTP) was explored as a measure and could be considered from a public transportation system rider perspective. Duddu et al. (2014, 2019) evaluated OTP at a bus-stop level based on travel time and delay at previous bus-stops. However, there are no studies quantifying the association between a reliability measure like OTP and ridership at a bus-stop level.

The number of boarding and alighting passengers influence the dwell time at a bus-stop and OTP. The number of boarding passengers at a bus-stop indicates ridership activity at the bus-stop. Providing reliable bus service could increase ridership (say, number of boarding passengers per bus at bus-stop). Thus, this study focuses on exploring and examining the association between bus transit reliability (OTP) and the number of boarding passengers at bus-stop level. It bridges the gap by developing a systemic framework to understand the association between bus transit reliability and ridership (the number of boarding passengers) over time (the day of the week and time of the day), the direction of travel, and type of bus-stop.

3 Methodology

The city of Charlotte, one of the most populated cities and commercial hubs in North Carolina, USA, was chosen as the study area to understand the association between bus transit reliability and the number of boarding passengers. Charlotte is in the Piedmont region of North Carolina. It has seen a 52.5% increase in population since 2000 (estimated population is 877,279 in 2020). The average trip length is about 25 min in the Charlotte region, approximately equal to the average

travel time across North Carolina (Pulugurtha et al. 2019). Travel by car (personal vehicle) has the highest mode share; 76.6% drive alone and 9.8% carpool to work. About 3.4% of the total trips are public-transportation-related in the city of Charlotte, North Carolina (CDOT 2022).

The Charlotte Area Transit System (CATS) is the agency responsible for operating public transportation systems in Charlotte, North Carolina. The public transportation systems include bus and LRT. Only the bus transit system within the city limits was considered in this study. LRT was not considered as there is only one corridor with a relatively smaller number of stations in the study area. The methodology includes collecting bus arrival/departure and ridership information at bus-stop level, data processing, reliability computation, and analysis.

3.1 Data collection

The data for this study was obtained from CATS for the year 2017. There were 76 fixed bus service routes in the entire city. Out of these, 49 are local bus service routes, 18 are express bus service routes, and 9 are neighborhood bus service routes. The majority of the local bus routes are connected to/from the city's downtown/uptown and popular LRT stations. The city's downtown/uptown is where most of the business is located, and most work-related trips are observed to and from downtown/uptown.

A total of 49 local bus service routes were considered for analysis in this study, as they constitute the majority of connections within the city. The express routes were not considered in this study as they have a lower number of stops when compared to local routes of bus service; thereby, fewer records of both ridership and reliability data.

The data collected from CATS have some reliability data and/or ridership data for all the bus-stops in the city. However, a bus-stop was considered for analysis only if all 52 weeks of the reliability data and ridership data are available. Per this criterion, 394 bus-stops were identified and considered for analysis due to the availability of data for all 52 weeks in a year.

3.2 Bus transit reliability data and ridership data

Bus transit reliability data for a given bus-stop includes the actual arrival time, actual departure time, scheduled time, direction of travel, route number, service day, stop description, date, time of the day, trip start time, time, and geographical coordinates. The bus transit ridership data at a given stop includes the variables route number, direction of travel, stop description, number of boarding passengers, number of alighting passengers, date, trip start time, geographical coordinates, departure time, day of the week, and time of the day.

3.3 Data processing

Data processing was conducted in two steps. The first step involved identifying important bus transit reliability and ridership details for a typical weekday and weekend. The second step involved the preparation of an integrated database by processing the bus transit reliability and ridership data. The bus transit reliability and ridership data were processed using Python Pandas, and the type of bus-stop was identified using the ArcGIS platform.

As stated previously, OTP was considered as the measure of bus transit reliability. The bus transit system considered in this study has headways between 20 and 60 min based on the time of the day (morning peak, mid-day, evening peak, and night-time) and day of the week (weekday and weekend). The Transit Capacity and Quality Service Manual (TCQSM 3rd Edition) recommends OTP as a measure of reliability for all the bus headways greater than 10 min. The departure adherence is computed using Eq. 1.

$$\text{DepartureAdherence} = \text{ActualDepartureTime} - \text{ScheduledTime} \quad (1)$$

The OTP of a bus service for a given time period is measured as a percentage of the schedule deviations in departures at a bus-stop. The deviations are -1 to 5 min of the desired time of departure, i.e., no more than 1 min early and up to 5 min late (per TCQSM 3rd Edition). For example, consider a bus with the scheduled departure time along a given route at a given bus-stop is $6:20$ PM. The bus is said to be on time if it departs between $6:19$ and $6:25$ PM. For passengers alighting the bus, it gives adequate time to plan for their respective destinations or transfers during the journey. Additionally, the percentage of schedule deviations in departures at a bus-stop based on -1 to 3 min of the desired time of departure was also computed and evaluated in this study.

With the obtained values of departure adherence, the OTP percentages were computed at each bus-stop using the framework shown in Fig. 1.

The number of passengers boarding at selected bus stops was captured using automatic passenger counters. The ridership data was processed to compute the

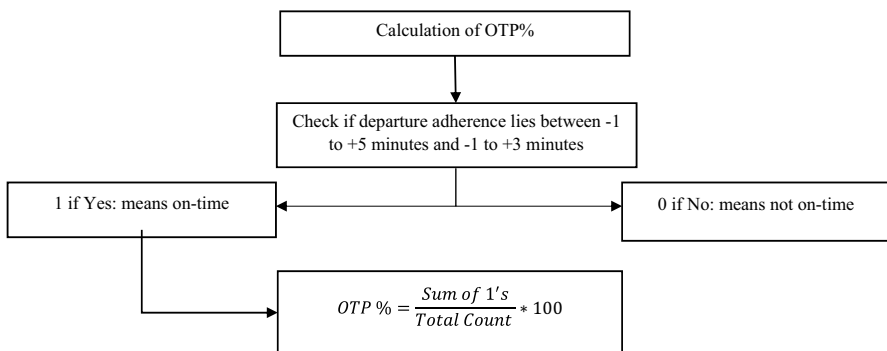


Fig. 1 Computation of OTP percentage

average number of boarding passengers at each bus-stop based on the analysis scenario (day of the week, time of the day, direction of travel and type of the bus-stop). The ridership data at bus-stop level was captured for a typical weekday and weekend for 52 weeks in a year. First, the total number of boarding passengers at each bus-stop was computed. Then, the average number of boarding passengers per bus at bus-stop i was computed using Eq. 2.

$$\text{Average \# of boarding passengers per bus} = \frac{\text{Total \# of boarding passengers at the bus-stop}}{\text{Total \# of trips at the bus-stop}} \quad (2)$$

3.4 Preparation of the integrated database

The bus transit reliability and the ridership data were processed separately to identify the necessary variables for the analysis. To develop an integrated database, the common and unique variables in both the bus transit reliability and ridership data were used as the matching fields. They are: route number, direction of travel, and stop description.

The route number is a unique number assigned to each local bus route in the city limits and the stop description is the name of the bus-stop serving a local route. The direction of travel describes the direction of the trip, which can either be inbound, outbound, north, south, east, or west in the city. The stop description and the route number are used to prepare the integrated database because a route could have multiple bus-stops. To capture the data for all the bus-stops along a route, both route number and stop description are used as matching fields.

The integrated database consists of variables such as the direction of travel, the route number, stop description, date, time of the day, latitude, longitude, bus transit reliability, average number of boarding passengers per bus, and the average number of alighting passengers per bus. The Pearson correlation coefficient analysis was conducted by segregating the integrated database for each analysis scenario (day of the week, time of the day, direction of travel and type of the bus-stop).

A typical weekday and weekend were considered for the analysis by day of the week. A total of four times of the day were considered and filtered based on the trip start time (morning peak: 7:00–9:00 AM, mid-day: 12:00–2:00 PM, evening peak: 5:00–7:00 PM and night-time: 8:00–10:00 PM) for analysis by time of the day. Inbound and outbound are the two directions considered as spatial indicators for the analysis by the direction of travel. Inbound direction trips are from sub-urban areas to the City Transit Center (CTC), whereas outbound trips are from CTC to sub-urban areas.

The presence of intermodal transit services within a city influences the ridership throughout the city. This could be attributed to transfers and coordination in the operational services of the systems (say, bus and LRT). The selected bus-stops are geospatially distributed in the study area and were, therefore, classified into different categories, by the type of bus-stop, accounting for multimodality and variation in ridership. They are (1) all bus-stops near LRT stations [bus-stops within 0.4 km (0.25 mile) radial buffer of an LRT station], (2) LRT-related transit centers, (3) other bus-stops near LRT stations, (4) all other bus-stops (excluding LRT-station-related

ones). Figure 2 shows the study area, the location of bus-stops and the CATS network.

3.5 Analysis

A descriptive analysis was conducted to identify possible outliers and anomalies in the data. The minimum, median, mean, maximum, and standard deviation of bus transit reliability and the average number of boarding passengers per bus were computed and examined. Table 1 summarizes the descriptive statistics of the considered bus transit reliability and the average number of boarding passengers per bus by day of the week and time of the day. Bus-stops with greater than 30 records were considered for the analysis. The mean value of BTR (-1 to 5 min) is about 74–76% and the mean value of BTR (-1 to 3 min) is about 56–58%. This indicates that the data of BTR (-1 to 3 min) is closer to normal distribution than that of BTR (-1 to 5 min). Hence, the normality test was performed with BTR (-1 to 5 min), BTR (-1 to +3 min) and an average number of boarding passengers per bus.

A sample normal distribution diagram (for weekday morning peak hour) is shown as Fig. 3. In Fig. 3, the y-axis of the histogram shows how frequently the values on the x-axis occur in the data. Here, the x-axis is the value of BTR (-1 to 3 min) and the y-axis is the number of times the values of BTR (-1 to 3 min) occur in the morning peak hour data of a typical weekday. The histogram plot indicates that the data may be normally distributed. A normality

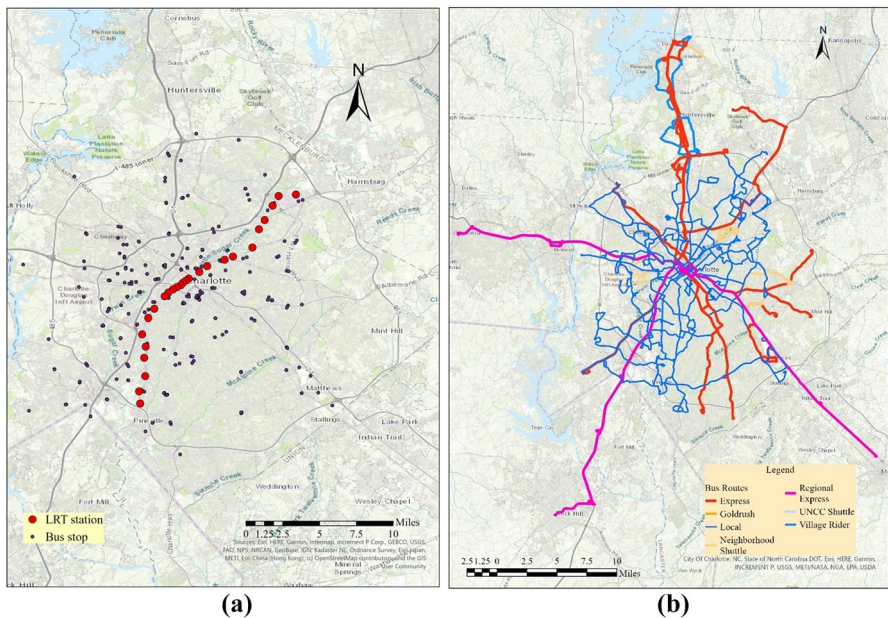


Fig. 2 a Study area showing bus-stop and LRT station locations, b Charlotte Area Transit System (CATS) network

Table 1 Descriptive statistics of bus transit reliability and average # of boarding passengers per bus

Time of the day	Variable	Minimum		Median		Mean		Maximum		Std. Dev.	
		Weekday	Weekend	Weekday	Weekend	Weekday	Weekend	Weekday	Weekend	Weekday	Weekend
All data	BTR (-1 to 5 min)	9.85	13.07	78.75	80.96	74.76	76.20	100	96.97	14.94	15.43
	BTR (-1 to 3 min)	1.57	11.57	59.63	61.05	58.42	59.54	90.38	90.91	15.14	16.28
Morning peak	Average # of boarding passengers/bus	0.00	0.00	0.95	0.92	2.09	2.14	22.32	25.89	3.54	3.58
	BTR (-1 to 5 min)	5.94	2	77.80	86	74.13	77.84	98.99	97.93	16.95	21.60
Mid-day	BTR (-1 to 3 min)	3.90	2	56.91	66.45	56.20	63.26	94.67	96.70	17.72	21.45
	Average # of boarding passengers/bus	0	0	0.73	1	2.22	2.59	25.64	23.33	4.01	4.14
Evening peak	BTR (-1 to 5 min)	5.62	7.89	81.91	77.55	77.33	72.89	100	96.94	17.08	18.19
	BTR (-1 to 3 min)	3.78	5.79	62.57	55.99	61.26	55.23	95.92	94.90	18.10	19.46
Night-time	Average # of boarding passengers/bus	0	0	1.13	1.30	2.47	2.64	24.08	23.29	4.32	4.01
	BTR (-1 to 5 min)	45.44	6	80.51	76.61	76.72	72.71	93.19	97.22	13.52	15.68
Night-time	BTR (-1 to 3 min)	30.12	6	59.35	57.15	61.01	55.16	83.75	91.61	14.79	17.39
	Average # of boarding passengers/bus	0	0	1.69	0.93	2.36	2.99	12.78	33.39	2.93	5.26
Night-time	BTR (-1 to 5 min)	3.21	20.19	82.37	77.93	77.37	73.96	97.83	99.50	16.98	16.80
	BTR (-1 to 3 min)	1.60	7.69	62.31	56.20	60	56.32	94.63	95.54	17.33	19.30
Night-time	Average # of boarding passengers/bus	0	0	1.15	1.06	2.54	2.73	23.28	27.39	4.38	4.55

BTR is bus transit reliability

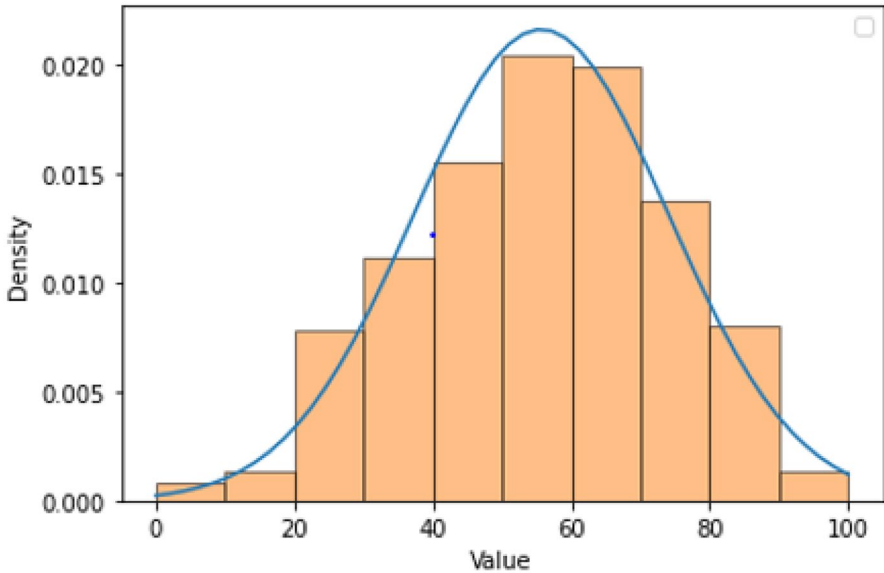


Fig. 3 Sample normal distribution diagram for morning peak hour data—weekday

test was performed to examine whether the data is normally distributed or not. D'Agostino's Pearson K^2 Test was conducted to determine if the data distribution departs from the normal distribution (D'Agostino 1986; Albassam et al. 2021).

The test results in summary statistics like the skewness (quantifies asymmetry in the distribution) and Kurtosis (quantifies the distribution in the tail). The null hypothesis is defined as the data is normally distributed. If the p-value is greater than the alpha (0.05 in this case) then the null hypothesis is accepted. Table 2 summarizes the D'Agostino's Pearson K^2 test results for normality.

From the normality test results, it can be observed that the null hypothesis is rejected in a few cases for both bus transit reliability (-1 to $+5$ min) and bus transit reliability (-1 to $+3$ min). This may be due to outliers and/or the presence of high variations in data (a variation in bus transit reliability and the average number of boarding passengers per bus from one stop to another). It also emphasizes the need to examine the variations in the data by segregating by day of the week, time of the day, direction of travel, and the type of bus-stop.

Pearson correlation coefficients were used to examine the association between transit reliability and the average number of boarding passengers per bus for each segregated dataset. The correlation coefficients, which are significant at a 95% confidence level, were used for assessing the association. The Pearson correlation coefficients were classified into six categories: high positive correlation coefficient: >0.5 , moderate positive correlation coefficient: $0.3-0.5$, low positive correlation coefficient: $0-0.3$, low negative correlation coefficient: -0.3 to 0 , moderate

Table 2 Normality test results

Data classification	Variable	Weekday		Weekend	
		Statistic	P-value	Statistic	P-value
All data	BTR (-1 to 5 min)	17.67	< 0.01	32.09	< 0.01
	BTR (-1 to 3 min)	5.12	0.08	9.47	0.01
Morning peak	Average # of boarding passengers/bus	36.10	< 0.01	31.60	< 0.01
	BTR (-1 to 5 min)	23.44	< 0.01	44.02	< 0.01
Mid-day	BTR (-1 to 3 min)	3.73	0.16	7.85	0.17
	Average # of boarding passengers/bus	25.81	< 0.01	25.91	< 0.01
Evening peak	BTR (-1 to 5 min)	24.29	< 0.01	16.11	< 0.01
	BTR (-1 to 3 min)	5.96	0.05	3.47	0.18
Night-time	Average # of boarding passengers/bus	44.64	< 0.01	14.28	< 0.01
	BTR (-1 to 5 min)	8.12	0.12	14.50	< 0.01
Morning peak Inbound	BTR (-1 to 3 min)	6.97	0.03	3.76	0.15
	Average # of boarding passengers/bus	38.67	< 0.01	35.66	< 0.01
Outbound	BTR (-1 to 5 min)	16.94	< 0.01	9.63	0.01
	BTR (-1 to 3 min)	2.75	0.25	5.90	0.05
Mid-day	Average # of boarding passengers/bus	14.81	< 0.01	17.56	< 0.01
Morning peak Inbound	BTR (-1 to 5 min)	17.19	< 0.01	31.07	< 0.01
	BTR (-1 to 3 min)	4.53	0.10	6.74	0.03
Outbound	Average # of boarding passengers/bus	5.17	0.08	5.96	0.05
	BTR (-1 to 5 min)	3.76	0.15	16.28	< 0.01
Mid-day	BTR (-1 to 3 min)	0.68	0.71	3.19	0.20
	Average # of boarding passengers/bus	71.56	< 0.01	23.11	< 0.01

Table 2 (continued)

Data classification	Variable	Weekday		Weekend		
		Statistic	P-value	Statistic	P-value	
Inbound	BTR (-1 to 5 min)	24.30	< 0.01	10.93	< 0.01	Rejected
	BTR (-1 to 3 min)	8.76	0.59	4.90	0.09	Accepted
Outbound	Average # of boarding passengers/bus	15.72	< 0.01	2.84	0.24	Accepted
	BTR (-1 to 5 min)	11.19	< 0.01	6.67	0.04	Rejected
	BTR (-1 to 3 min)	2.55	0.28	0.22	0.90	Accepted
	Average # of boarding passengers/bus	41.99	< 0.01	29.25	< 0.01	Rejected
Evening peak						
Inbound	BTR (-1 to 5 min)	8.13	0.02	22.34	< 0.01	Rejected
	BTR (-1 to 3 min)	4.52	0.10	3.85	0.15	Accepted
Outbound	Average # of boarding passengers/bus	4.98	0.08	63.40	< 0.01	Rejected
	BTR (-1 to 5 min)	4.68	0.10	3.69	0.16	Accepted
	BTR (-1 to 3 min)	3.61	0.16	1.11	0.57	Accepted
	Average # of boarding passengers/bus	70.19	< 0.01	40.24	< 0.01	Rejected
Night-time						
Inbound	BTR (-1 to 5 min)	14.83	< 0.01	8.68	0.01	Rejected
	BTR (-1 to 3 min)	3.83	0.15	15.00	< 0.01	Rejected
Outbound	Average # of boarding passengers/bus	0.14	0.93	27.62	< 0.01	Rejected
	BTR (-1 to 5 min)	10.41	0.01	2.71	0.26	Accepted
	BTR (-1 to 3 min)	2.24	0.33	0.51	0.77	Accepted
	Average # of boarding passengers/bus	31.79	< 0.01	27.52	< 0.01	Rejected

BTR is bus transit reliability

Table 3 Association between bus transit reliability and average # of boarding passengers per bus by day of the week

Day of the week	BTR (-1 to 5)	BTR (-1 to 3)
Weekday	0.30	0.23
Weekend	0.27	0.23

BTR is bus transit reliability

Table 4 Association between bus transit reliability and average # of boarding passengers per bus by day of the week and time of the day

Day of the week	Time of the day	BTR (-1 to 5)	BTR (-1 to 3)
Weekday	Morning Peak	0.31	0.26
	Mid-day	0.29	0.20
	Evening Peak	0.30	0.18
	Night-time	0.31	0.24
Weekend	Morning Peak	0.33	0.30
	Mid-day	0.39	0.35
	Evening Peak	0.31	0.25
	Night-time	0.32	0.27

BTR is bus transit reliability

negative correlation coefficient: -0.5 to -0.3 , and high negative correlation coefficient: $< (-0.5)$.

4 Results

The results from Pearson correlation coefficient analyses are discussed in this section.

4.1 Association between bus transit reliability and the average number of boarding passengers per bus by day of the week

Table 3 shows that there exists a low positive correlation between the average number of boarding passengers per bus and bus transit reliability based on bus transit reliability (-1 to 5 min) and bus transit reliability (-1 to 3 min) on weekdays and weekends. This indicates that an increase in bus transit reliability increases the ridership. A similar analysis was carried out for all the selected times of the day and by the direction of travel.

4.2 Association between bus transit reliability and the average number of boarding passengers per bus by day of the week and time of the day

From Table 4, there exists a moderately positive correlation between the bus transit reliability and the average number of boarding passengers per bus for the morning peak and night-time hours on a weekday. A low positive correlation was observed for the mid-day and evening peak hours. For the weekend, the correlation is moderately positive for all the selected times of the day.

Overall, the results show a significant positive correlation between bus transit reliability and the average number of boarding passengers per bus for all the times of the day and days of the week.

4.3 Association between bus transit reliability and the average number of boarding passengers per bus by day of the week, time of the day, and direction of travel

From Table 5, it can be observed that the correlation is stronger in the inbound direction during the morning peak, mid-day, and night-time hours than the analysis conducted based on the day of the week and time of the day (moderately positive to high positive correlation).

Table 5 Association between bus transit reliability and average # of boarding passengers per bus by day of the week, time of the day, and direction of travel

Day of the week	Time of the day	Direction of travel	BTR (-1 to 5)	BTR (-1 to 3)
Weekday	Morning peak	Inbound	0.57	0.56
		Outbound	0.35	0.31
	Mid-day	Inbound	0.52	0.46
		Outbound	0.36	0.26
	Evening peak	Inbound	0.50	0.43
		Outbound	0.45	0.32
Night-time	Inbound	0.53	0.48	
	Outbound	0.37	0.31	
Weekend	Morning peak	Inbound	0.52	0.39
		Outbound	0.35	0.34
	Mid-day	Inbound	0.46	0.30
		Outbound	0.48	0.49
	Evening peak	Inbound	0.38	0.29
		Outbound	0.37	0.33
Night-time	Inbound	0.39	0.31	
	Outbound	0.41	0.37	

BTR is bus transit reliability

The correlation results considering the temporal analysis indicate a statistically significant relationship between bus transit reliability and the average number of boarding passengers per bus. To explore how the proximity and location of bus stops influence the association between bus transit reliability and the average number of boarding passengers per bus, the analysis was performed by considering the type of bus-stop.

4.4 Association between bus transit reliability and the average number of boarding passengers per bus by day of the week, time of the day, and the type of bus-stop

It is observed from Table 6 that a high positive correlation exists between the bus transit reliability and the average number of boarding passengers per bus during peak hours of the day when data for all bus-stops near LRT stations was used for the analysis. The trend was observed to be the same for both weekend and weekday. Data for LRT-related transit centers also exhibited a high-positive correlation for both weekday and weekend. Data for bus-stops near LRT (all bus-stops near LRT excluding the transit centers) exhibited a moderate positive correlation for the morning peak, while data for LRT-related transit centers exhibited a high positive correlation for mid-day, evening peak, and night-time hours. Other bus stops exhibited moderate boarding (ridership) activity because they usually have the characteristics of a normal bus stop.

4.5 Association between bus transit reliability and the average number of boarding passengers per bus by day of the week, time of the day, the type of bus-stop and direction of travel

For a weekday, it is observed from Table 7 that all bus stops near LRT stations exhibited a high positive correlation between bus transit reliability and the average number of boarding passengers per bus for all selected times of the day. LRT-related transit centers did not exhibit any significant results in the correlation analysis when considered by the direction of travel. Bus stops near LRT (all bus stops near LRT excluding the transit centers) exhibited a high positive correlation for all selected times of the day in the outbound direction of travel. Bus stops near LRT connect passengers from the LRT stations with their origins and destinations and, thus, exhibited a high positive correlation between bus transit reliability and the average number of boarding passengers per bus.

Other bus stops have a moderate ridership activity in both outbound and inbound directions of travel. The association between bus transit reliability and the average number of boarding passengers per bus was found to be moderately positive during all selected times of the day for a weekday. For the weekend, no significant correlation between bus transit reliability and the average number of boarding passengers per bus was observed, as the ridership patterns are not specific to a type of bus stop. For all bus stops near LRT, a highly positive correlation

Table 6 Association between bus transit reliability and average # of boarding passengers per bus by day of the week, time of the day, and the type of bus-stop

Day of the week	Time of the day	Type of bus-stop	BTR (-1 to 5)	BTR (-1 to 3)
Weekday	Morning peak	All bus-stops near LRT stations	0.54	0.46
		LRT-related transit centers	0.73	0.69
		Other bus-stops near LRT stations	0.50	0.40
		All other bus-stops (excluding LRT-related)	0.44	0.47
	Mid-day	All bus-stops near LRT stations	0.58	0.47
		LRT-related transit centers	0.79	0.75
		Other bus-stops near LRT stations	0.59	0.53
		All other bus-stops (excluding LRT-related)	0.42	0.36
	Evening peak	All bus-stops near LRT stations	0.56	0.45
		LRT-related transit centers	0.79	0.75
		Other bus-stops near LRT stations	0.56	0.51
		All other bus-stops (excluding LRT-related)	0.29	0.17
	Night-time	All bus-stops near LRT stations	0.59	0.48
		LRT-related transit centers	0.79	0.75
		Other bus-stops near LRT stations	0.58	0.49
		All other bus-stops (excluding LRT-related)	0.43	0.41
Weekend	Morning peak	All bus-stops near LRT stations	0.53	0.50
		LRT-related transit centers	0.74	0.72
		All other bus-stops (excluding LRT-related)	0.37	0.30
	Mid-day	All bus-stops near LRT Stations	0.63	0.59
		LRT-related transit centers	0.82	0.80
		All other bus-stops (excluding LRT-related)	0.36	
	Evening peak	All bus-stops near LRT Stations	0.44	0.37
		LRT-related transit centers	0.65	0.60
		All other bus-stops (excluding LRT-related)	0.27	
	Night-time	All bus-stops near LRT Stations	0.48	0.40
		LRT-related transit centers	0.69	0.62
		All other bus-stops (excluding LRT-related)	0.27	

BTR is bus transit reliability. Blank cells indicate that the correlation coefficient is not significant at a 95% confidence level

Table 7 Association between bus transit reliability and average # of boarding passengers per bus by day of the week, time of the day, type of bus-stop and direction of travel

Day of the week	Time of the day	Type of bus stops	Direction of travel	BTR (-1 to 5)	BTR (-1 to 3)
Weekday	Morning peak	All bus stops near LRT stations	Inbound	0.66	0.62
			Outbound	0.52	0.45
		Bus stops near LRT	Inbound	0.70	0.60
	Outbound		0.45	0.47	
	Other bus stops		0.72	0.70	
	Mid-day	All bus stops near LRT stations	Inbound	0.51	0.68
Outbound			0.67	0.65	
Other bus stops			0.35	0.69	
Bus stops near LRT		Inbound	0.71	0.46	
		Outbound	0.67	0.67	
		Other bus stops	0.67	0.27	
Evening peak	All bus stops near LRT stations	Inbound	0.71	0.69	
		Outbound	0.46	0.63	
		Other bus stops	0.67	0.67	
	Bus stops near LRT	Inbound	0.27	0.63	
		Outbound	0.67	0.67	
		Other bus stops	0.67	0.67	
Night-time	All bus stops near LRT stations	Inbound	0.71	0.69	
		Outbound	0.51	0.67	
		Other bus stops	0.67	0.69	
	Bus stops near LRT	Inbound	0.67	0.67	
		Outbound	0.67	0.67	
		Other bus stops	0.67	0.69	

Table 7 (continued)

Day of the week	Time of the day	Type of bus stops	Direction of travel	BTR (-1 to 5)	BTR (-1 to 3)
Weekend	Morning peak	All bus stops near LRT stations	Inbound	0.52	
			Outbound		
Mid-day		Other bus stops	Inbound		
			Outbound		
		All bus stops near LRT stations	Inbound	0.50	
			Outbound	0.55	0.52
Evening peak		Other bus stops	Inbound		
			Outbound		
		All bus stops near LRT stations	Inbound	0.60	0.56
			Outbound		
Night-time		Other bus stops	Inbound	0.36	
			Outbound		
		All bus stops near LRT stations	Inbound	0.59	0.47
			Outbound		
		Other bus stops	Inbound		
			Outbound		

BTR is bus transit reliability. Blank cells indicate that the correlation coefficient is not significant at a 95% confidence level

and moderately positive correlation was observed for both, inbound and outbound directions of travel.

5 Conclusions

An evaluation of the association between bus transit reliability and the average number of boarding passengers per bus is presented in this paper. The analysis was carried out at two levels: temporally by considering day of the week and time of the day, and spatially by considering proximity and location of the bus-stop. The temporal analysis was used to assess if the ridership varied with day of the week and time of the day. The spatial analysis was used to assess the overall perspective of the bus-stop facility and its influence on the association between bus transit reliability and the average number of boarding passengers per bus. Three hundred and ninety-four geospatially distributed bus stops in the city of Charlotte, North Carolina, USA were considered in this study. The OTP percentage is considered as an indicator of bus transit reliability.

Two days of the week, four times of the day, two directions of travel, and five types of bus stops were considered for the Pearson correlation coefficient analysis. Some differences (in general, lower correlation) were observed when -1 to 3 min of the desired time of departure was used to compute OTP instead of -1 to 5 min of the desired time of departure.

The findings indicate that bus transit reliability is positively associated with the average number of boarding passengers per bus over the weekdays and weekend. Specifically, the average number of boarding passengers per bus during morning peak and night-time hours of a typical weekday are highly correlated with bus transit reliability, emphasizing concentrated work trip patterns. In the case of the weekend, a moderate positive correlation between bus transit reliability and the average number of boarding passengers per bus was observed for the selected times of the day.

The direction of travel was further used for examining the association between bus transit reliability and the average number of boarding passengers per bus. A highly positive correlation was observed for the inbound direction during morning peak hours on a typical weekday, potentially owing to work trip patterns towards the city's central business district (downtown/uptown). Similarly, a positive correlation between bus transit reliability and the average number of boarding passengers per bus for the outbound direction was observed during night-time hours, potentially due to work-to-home trips.

The presence of intermodal transit services in the city influences overall transit ridership. These intermodal transit services require a definite coordination in their operations for better reliability. The Pearson correlation coefficient analysis was conducted by classifying the data based on the type of bus stop to understand the influence of location parameters. The results indicate that transit centers and bus stops near LRT stations (typically categorized as high activity bus stops) are positively correlated with the average number of boarding passengers per bus. A moderate

positive correlation between bus transit reliability and the average number of boarding passengers per bus was observed at bus stops located away from LRT stations.

Many mid-sized urban areas in the United States are moving towards improving public transportation services. Therefore, analyzing the public transportation reliability measures and examining their association with the ridership (the average number of boarding passengers per bus at a bus stop in this study) will give a better understanding of how reliable services stimulate the use of public transportation on a large scale. It also helps assess the relationship and proactively implement solutions to increase ridership and maximize benefits from transit service improvement investments.

The delay at previous bus stops in addition to dwell times influence bus transit reliability at a bus stop. Likewise, traffic volume, seasonal variations, driving behavior, bus characteristics such as age, acceleration and deceleration characteristics, and other non-recurring congestion-related factors (crash, breakdown of a vehicle, etc.) along the route influence bus transit reliability at a bus stop. In addition, joint effects or interactions influence the relationships. Capturing, integrating, and analyzing these additional factors merit further investigation.

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Data availability The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declaration

Conflict of interest This paper is disseminated in the interest of information exchange. The views, opinions, findings, and conclusions reflected in this paper are the responsibility of the authors only and do not represent the official policy or position of the University of North Carolina at Charlotte or other entity. The authors are responsible for the facts and the accuracy of the data presented herein. This paper does not constitute a standard, specification, or regulation.

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