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Impact of stops for bus delays on routes

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Abstract. In this paper bus travel time and delay is significant measures in public transportation. This research aims to explore impact of stops for the selected bus route and to find some simple suitable solutions to reduce the travel time and minimize delays for scheduling preferences of travellers. Delays data were collected using automatic vehicle location system (GPS technology) for the bus route #51 in Tashkent. Based on the collected GPS data were proposed the developed a linear and a logistic multivariate regression model. Travel time reliability were estimated regarding to a multivariate regression models and performed. The result shows that very good statistical suitable as expected and thus can be used in the public transportation to determine any travel time using real-time and available offline data. These outcomes, in the future it is expected that will be applicable and more efficient bus public transportation system in Tashkent.

1. Introduction

In fact, the faster growth of motorization and urbanization requires an urgent measure for more effective and safer urban transport system. Traffic congestion is serious problem around the world. Global greenhouses gases (GHGs) from transportation in passenger and freight traffic accounts one of the main parts of all emissions and it is fast-growing sector worldwide. The share of transport waste could double by 2050, not only due to fuel dependence, also due to the growing demand for mobility and freight traffic volume.

The rapid increase in the number of cars is leading to traffic congestion. Traffic congestion affects, firstly, spending extra time to the destination by passengers, and secondly, the excessive travel distances of cars, consequently, increased fuel consumption, which is major impact on the environment and urban air pollution. In general, it causes socio-economic losses. These losses cost is average of 138.2 million US dollars a year in Tashkent [1]. One of the most important issues is the proper management of traffic flow and efficient organization of urban transports in the city. The growing population of Tashkent and the frequent congestion of city during rush hours are particularly deteriorating the quality of transport services.

At the time when the population's demand for transport is growing, it is important to provide fast and quality service of public transport. Public transport is a vehicle that competes directly with private cars. Nowadays, reducing traffic congestion is one of the most important challenge in Tashkent city. This led to challenge with the capacity of the road network. In Tashkent the growth in motorization is complicated by the crisis of urban mass transport, which is characterized by a sharp drop passenger turnover in past decade. Bus companies operate under stochastic conditions. Stochastic conditions depend on the number of factors and complexity of the links between the factors. These factors are passenger fluctuation and traffic congestion in the city. Particularly, during peak hours travellers spend extra time for traffic delays. Traffic delays are much worse than expected delays or less tolerant of unexpected delays to be late for going to destination. Travel time and delay are important to both travellers and operating bus companies. Operating bus companies that face unexpected delay may reduce number of users in the public transport for time delivery. Travel time and delay is one of the indicators of the quality of transport services and reflects the efficiency of the transport system.

Increasing the efficiency of bus transportation is one of the urgent problems. The development of measures to solve this problem by studying the influencing factors and their quantitative assessment is considered a priority. At the aforementioned challenges, whole range of issues related to improvement efficiency of urban public transport, as determines the relevance of the topic of this research.

The main purpose of this study was to propose delay measures that can consider influence of random traffic congestion and unscheduled bus stops on the route. Another purpose of this study is to develop a methodology for collecting, processing and evaluating information on the travel time of shuttle buses using GPS technology. The advantage of this method is that possible to estimate travel times in terms of stops or routes, and also relatively inexpensive and convenient compared to existing methods. This methodology allows you to organize high-quality transport services for the population, quickly evaluate and analyse, daily adjust the route schedule or develop new routes, change working hours and reduce social costs.

2. Literature Review

Most of the research in transportation field of over the past few decades have been devoted to assessing the traffic congestion [2-4], transportation planning for climate change mitigation [5, 6] and improving the urban transportation efficiency [7-15]. These questions directly depend on the travel time and delays.

In the research work of the authors [16, 17], the main attention is paid to the factors influencing travel time. Travel time and variability is one of the most important and difficult factors in transportation systems. Travel time depends on the dynamic variability of traffic flows and passenger fluctuations [16-20]. As a result, such relationships reflect the interactions between supply and demand for transportation. The literature recognizes that the impact of traffic flow is another important variable that influences travel time and variability. In theory, an increase in traffic flow could create additional delays for transportation due to congestion along the route. However, many studies [17, 18] have examined the effect of traffic flow on travel time using variables such as "time of day" or "direction of travel". It should be clarified that the factors presented are highly interrelated.

The volatility of demand and supply of road traffic, which are highly dependent on each other, lead to variability in travel time. Accordingly, this variability can potentially affect the travel time and delays and the quality of services provided to passengers. The variability of travel time and delays is influenced by both internal and external factors in the operation of public transport. Internal factors include the type and capacity of the vehicle, the ticket payment system and the number of bus stops along the route. External factors are closely related to the dynamic variability of traffic flows and passenger fluctuations. Traffic conditions are affected by the level of congestion during rush hours or road accidents [9]. Studies show that variability in travel time increases during peak hours, due to increased passenger demand.

From the point of view of travellers, inaccuracy in real-time information increases uncertainty for decisions about delay and route selection, and discourages the use of public transport. Therefore, travel time and delay are important to improve the predictability of transport services and the accuracy of travel times.

The travel time reliability measures have been used on many studies [21-25]. They include: The difference between expected arrivals and scheduled arrivals; The standard deviations of arrival times; The probability of early departure time; The probability of arrival time; Probability of arrival time that given time range. Different operating companies choose different reliability measurements according to their needs. Travel time and delays have calculated for time periods, days or seasons of interest. The reliability measures are Buffer Index, Travel Time Index, Planning Time Index, On-time arrival, 95th Percentile Travel Time and others.

In this regard, there are many papers adopted a number of approaches focused on several travel time reliability measures in the literature, there exists a debate on which approach is more effective. Findings an effective measure that provide good understanding of current existing condition is involved an analysis of the merits to transportation decision and policy makers. In fact, travel time and delay are as an important indicator for transportation system in their performance evaluations.

3. Study Route Description

This route was chosen due to the fact that all buses are fully equipped with GPS devices and both directions of street along is one of the heavy traffic streets. Some segments of the selected route consist of 4 lanes in both directions. Figure 1 shows google map view of the selected bus route #51 in Tashkent. The main part of the route is located on the major arterial roads of the city. Traffic volumes along the street range from 20000 to 30000 vehicles a day. Average car speed along street is 35 km/h. The study route of cycle distance is 28.5 km.

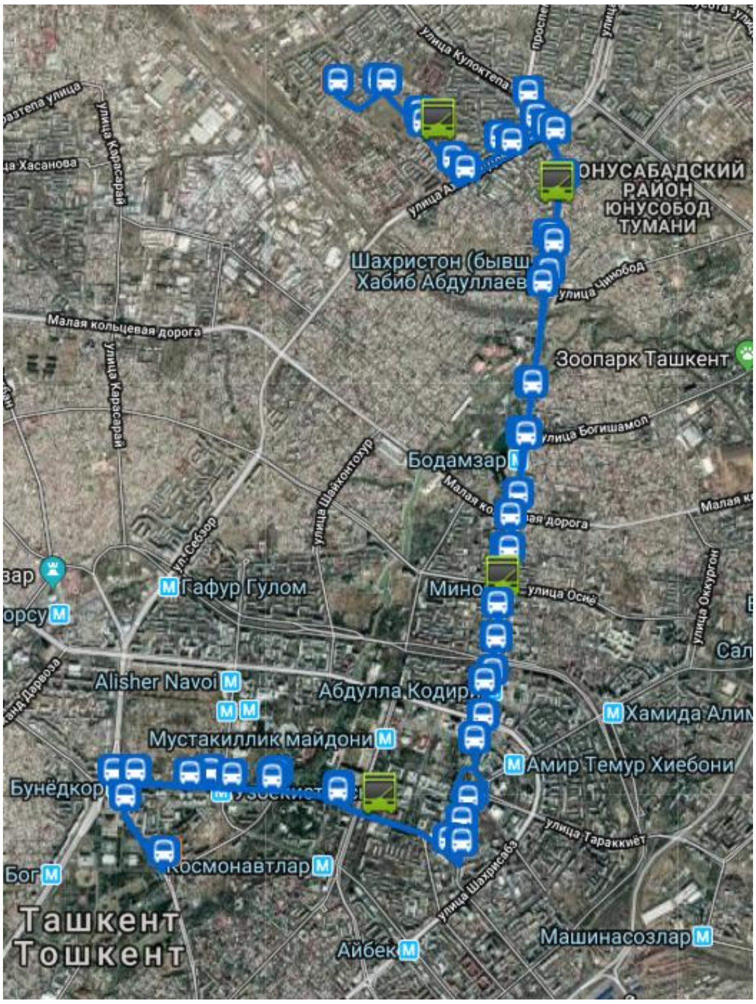

Figure 1. Google map of the study route

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Route characteristics:

- Length of the route is 13.9 km for a forward A-direction with 22 stops (Yunusabad-6 kv - Beshagach square);
- Length of the route is 14.6 km for the backward B-direction with 26 stops (Beshagach - Yunusabad-6kv square);
- Number of signalized intersections along the route is 18;
- There are many unregulated intersections and pedestrian crossings;
- The operating time of the route is from 5:30 to 22:00;
- Headway is 12-13 minutes during peak hours.

4. Methodology

Research methodology consist of three steps: data recording, data extraction and assessment (data analysis). Figure 2 illustrates data processing from collection to evaluation stage.

Figure 2. Data processing: from collection to evaluation stage

There is method for collecting bus delay data using global positioning system (GPS) equipment. Using this procedure, a bus is driven along the selected route while a recorder collects cumulative travel time, dwell times, stop times, and delay times. Collecting geolocated travel data includes datasets containing point locations, bus speed, date and time.

Based on the data collected, peak and non-peak hours were determined for the route being surveyed. Morning (afternoon) peak periods are from 7:00 am to 9:00 am (5:30 pm to 7:30 pm). The travel time data for the selected route is the same for each day and was performed under normal conditions. totally data was collected 125 trips a day by operating 7 buses and 90 trips by operating 6 buses on weekends.

In the raw data, there are whole of day all data tracked by the bus while is parked in a depot at night times and waiting times at terminals during and the lunch times. Some of them data is no need for analysis in our study. It should be filtered in our case study. We used only data for our developed an algorithm (Figure 3) to get results. In this study the algorithm is used as input to determine run and stop time of an individual trip of bus. Thus, the data received from all procedure buses are used as detailed below.

The first step in this process is to assign a unique identification number to individual bus trips. In the second step, identifiers, latitude and longitude of static objects are assigned. To do this, the latitude and longitude data of all static (bus stops, all intersections, pedestrian crossings and others) objects on the route is determined. In the third step, the collected data is saved to the database. In the next step, it is determined whether all data entry is complete. The fifth stage determines the speed of the bus and its current location. If the speed is higher than 0 km / h, the time of movement is determined, otherwise it checks the current location of the bus for compliance with the location of static objects. In case of a discrepancy between the location of the bus and the object, the data is recorded as the number and duration of implicit delays. In case of compliance, the bus location is checked for compliance with the locations of intermediate and final stops, and in case of compliance, the time of standing and downtime is determined, otherwise data on the number and duration of delays are entered into the database as explicit delays.

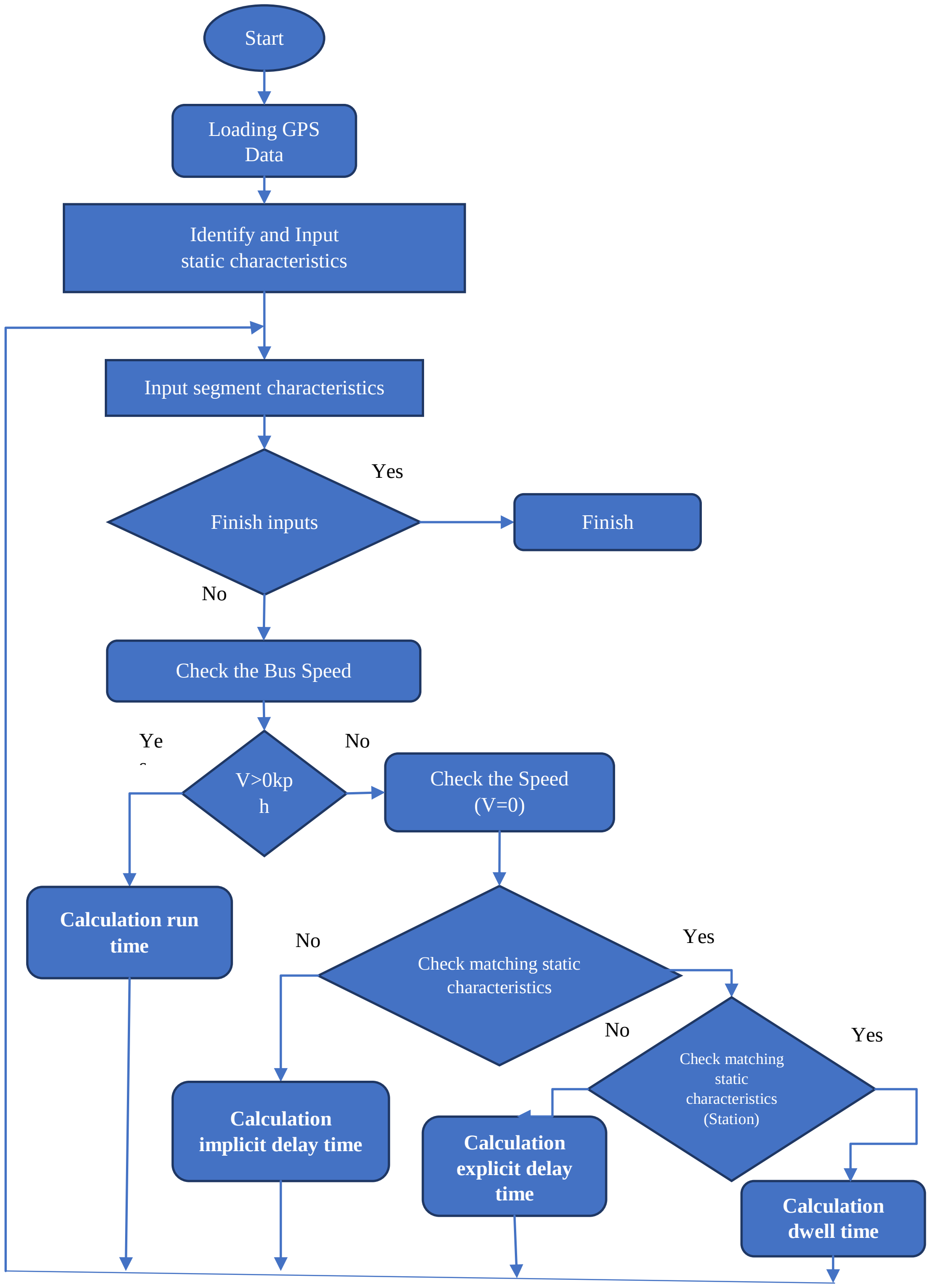

Figure 3. Program algorithm for determination run and stop times on the route

Travel delay is a timed measure of transportation performance and it can be caused by different conditions. Also delay can be categorized explicit and implicit form by the factors influencing travel delay. Travel delay is also one of the more quickly understand by transportation engineers and travellers. Figure 4 shows the general approach for estimation travel time and delay.

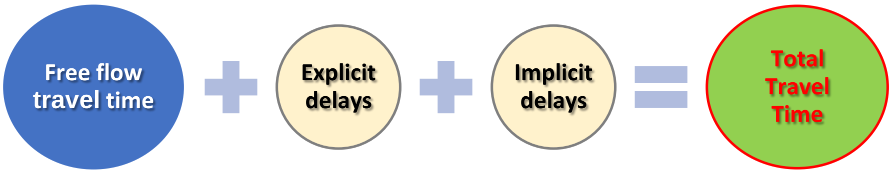

Figure 4. General approach

Free flow travel time – travel time is a normal bus trip without traffic congestion, no external and internal factors, like schedule adherence.
Explicit delays – delay is like systematic delays, it is additional travel time that can be expected.
Implicit delays – it is also additional travel time by unobserved dynamic factors that can be unexpected congestion, passenger fluctuations, bus failure and so on.
Figure 5 shows the conceptual model for analysis of travel time and delay on route level (terminal-to-terminal).

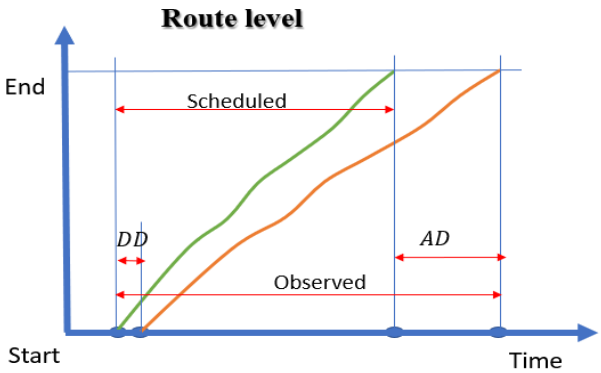

Figure 5. Conceptual model for analysis of travel delay.

Total travel time at the route level is formally expressed as:

$$TT_{travel} = \sum T_{runtime} + \sum T_{unschstop} + \sum T_{schstop} \tag{1}$$

Where, $T_{runtime}$ – running time, $T_{unschstop}$ – unscheduled stop time and $T_{schstop}$ – scheduled stop time.
Travel time (TT) is duration of time period a route between two points of interest. It is defined as:

$$TT_{ij} = T_{arrival-j} - T_{departure-i} \tag{2}$$

Where, *i*- and *j*- *indexes* mean between any two stop *i* to stop *j* for a trip at a selected time interval, $T_{arrival-j}$ - arrival time at stop j and $T_{departure-i}$ - departure time at stop *i*.
Dwell time (DT) can be defined as spent time at stops for servicing to alighting and boarding passengers. It is time period at scheduled stop made. It is defined as the difference between the departure time and arrival time at same stops.

$$DT_i = T_{departure-i} - T_{arrival-i} \tag{3}$$

Where, $T_{departure-i}$ – departure time of bus at stop *i* and $T_{arrival-i}$-arrival time of bus at stop *i*.
Stop time (ST) is duration of time at unscheduled stop made.
Departure delay (DD) is defined as the difference between the scheduled departure time and actual departure time at same position.
Arrival delay (AD) is defined as the difference between the scheduled arrival time and actual arrival time at same position.

Delays are leads to poor bus service reliability. The research work was conducted basic statistical analyses to determine bus delay pattern using delay data for routes. Figure 6 shows the delays distribution for buses on the route #51. The delays for buses ranged from -11 to 25 minutes on this route. The median observed delay for buses was 4.5 minutes. The standard deviation of bus delays was subject to higher variation.

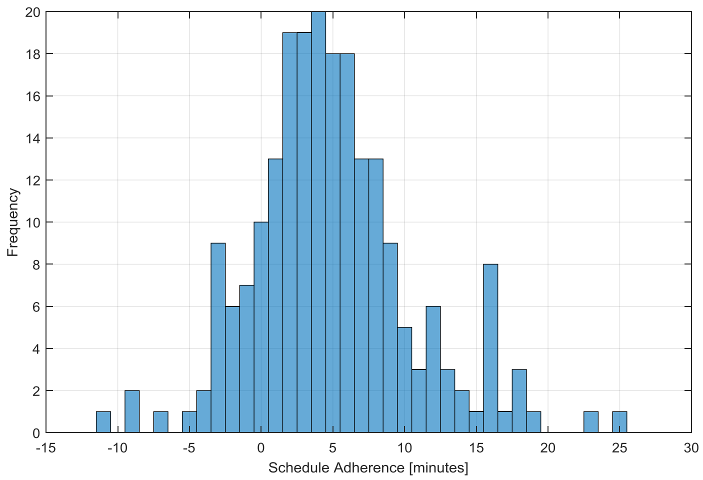

Figure 6. Histogram of scheduled adherence for the Route#51

Figure 7 shows the averaged results for 135 trips including the percentage average travel times components: moving and stopped times. Bus travel time includes moving, dwelling and stopping time.

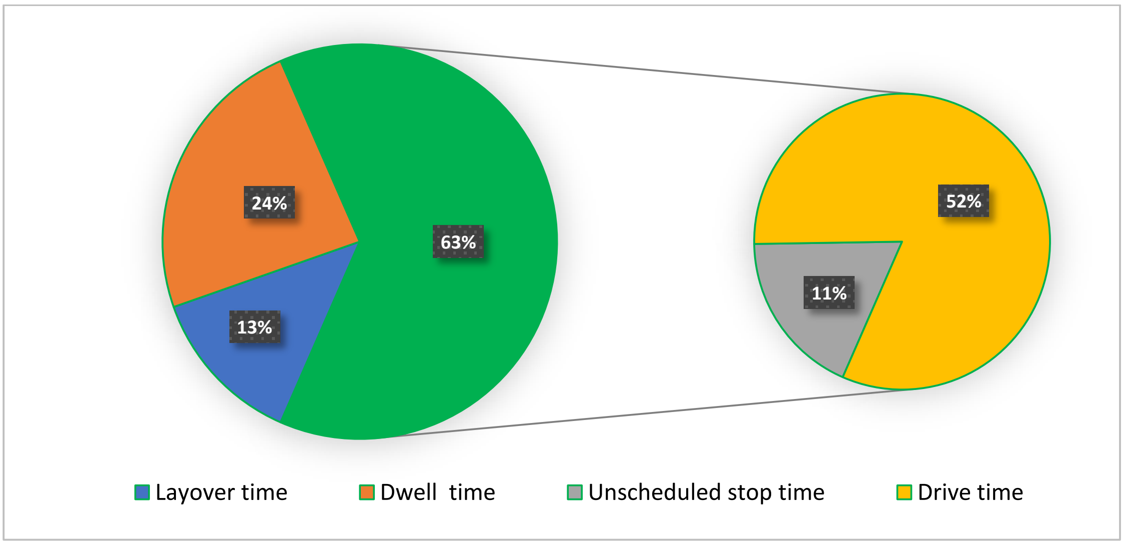

Figure 7. Average travel time components

5. Statistical Analysis

As aforementioned, on-time performance and arrival delay two indicators are key measures of bus travel time reliability. The first, on-time performance is the most recognized measure among operative company perspectives. It is defined on-time service within a time ranging from one minute early to three minutes late from the schedule. In practice, it is most relevant in conditions of infrequent service. The model measuring schedule adherence or on-time performance in travel time as logistic regression. The

second indicator is arrival delay. The delay is possible to represent by arrivals, it is the time difference between actual arrival time and planned arrival time. This, travellers arrive at random in relation to schedule service, here reliability can be better reflected than to schedule adherence.
This indicator is more proper in the circumstances for long distance routes, facing many traffic lights and regular traffic delays. On-time performance and delay are more applicable to low-frequency routes. This study gets insight into explicit and implicit factors influencing bus service reliability especially travel time and delay on the bus route. Both model measures are impacted by main factors involving departure delays, number of unscheduled stops made, dwell times, number of signalized intersection and others.
In the model representing a dependent variables Y_i as a linear function of several explanatory variables (Xi). Algebraically such the model is represented by the following general form:

$$Y_i = a_0 + a_1X_1 + a_2X_2 + a_3X_3 + a_4X_4 + a_5X_5 + a_6X_6 + \cdots + a_nX_n$$

Where, a_i – coefficients, n – number of independent variables.
The regarding variables for two models are notated and described in Table 1 and Table 2.

Table 1. Dependent variables

Notation	Variable name	Description
$\log\left({Y_i}/{Y_j}\right)$	On-time performance	Dummy variable (relative probability), if performed on-time =1, otherwise early or late =0 (bus arrivals is according to the bus schedule adherence, arrival to destination no more than 1 min early or no more than 3 min late)
Y_i	Delay	Arrival delay measured in minute (observed arrival time – scheduled arrival time)

Table 2. Independent variables

Name	Description
Direction	Binary variable for trip (1-Forward direction, 0-Backward direction)
AMpeak	Binary variable (1 = morning peak, if a bus operates between 7:00 am to 9:00 am and 0 = otherwise (off peak)
PMpeak	Binary variable (1 = if a bus operates between 17:30 pm and 19:30 pm and 0= otherwise)
DwellTime	Total number of passengers on boarding or alighting through all doors at a stop during a trip
SchStop	Actual stop that was made by bus during a trip designated stop
UnSchStop	Unscheduled stop occurs after an unscheduled stop along the trip
Closer	Binary variable equal to 1 if the bus stop placement is located near to an intersection, otherwise 0
Inlane	Binary variable equal to 1 if the stops occurred while operating in reserved lanes on road operation, otherwise 0
Signals	Number of signalized intersections
Unsignals	Number of unsignalized intersections, pedestrian crossings and others
DepDelay	Difference between observed and scheduled departure time at starting terminal (origin)

Consequently, the following hypotheses are inferred. Bus delay has expected to increase with the number of possible stops, number of actual stops, dwell time regarding to passenger activities on routes. Bus delays increase in the morning and evening peak hours for trips relative to off peak hours. Sometimes, periodic delays might be likely a positive effect on travel time. Departure delay measured at the beginning of the time point, it could be either positively or negatively related to travel time.

Alternatively, if delay is circumstantial and operators utilize recovery opportunities, delay could be inversely related to travel time. Departure delay at the beginning is expected to be more serious in these models. They can be used to assess the extent to which schedules are well designed to accommodate the various operating conditions along the route. A dummy variable for the direction of trips is included in the models to control for these variations. Finally, two dummy variables representing, respectively directions and peak hours are included to measure the differences between the operating environment among these time periods relative the non-peak time. For models we hypothesize that the same relationship exists with the independent variables.

6. Results and Discussions

The estimated results of on-time performance and delay indicators are shown in Table 3. All variable coefficients have expected and statistically significant at the 1% level except some characteristics, which is significant at the 5% level. The variable stop placement and locations is not included in the results due to statistical insignificance.

Table 3. Estimation results of models

Variables	Dependent variable	
	On-time performance	Delay
Constant	-4.397***	-17.391 ***
	(1.623)	(3.492)
Direction	0.611**	3.135 ***
	(0.276)	(0.579)
Departure delay	-0.092***	0.633 ***
	(0.017)	(0.022)
AMPeak	-0.567**	0.940 **
	(0.229)	(0.441)
PMPeak	-0.507**	0.664
	(0.241)	(0.483)
Unscheduled stop made	-0.301***	1.114 ***
	(0.033)	(0.051)
Scheduled stop made	0.236***	0.506 ***
	(0.067)	(0.143)
	Observations 755	Observations 755
	Log Likelihood -386.233	R2 0.679
	Akaike Inf. Crit. 786.465	Adjusted R2 0.676
		Residual Std. Error 4.906 (df = 748)
		F Statistic 263.674*** (df = 6; 748)
		Note: *p<0.1; **p<0.05; ***p<0.01

The results presented in Table 3 suggest the following about the causes of reliability on bus route#51:
Direction is found to be sensitive variable examined in relation to impact on reliability. The results for direction coefficient suggest that on-time performance indicator in an A-direction is 6.11 % less than that in B-direction.
AMpeak and PMpeak variables coefficients are -0.567 and -0.507 respectively suggesting it has one of the more sensitive and negative relationship with on-time performance. Change in on-time performance for 1 unit increase the peak hours variable values are decreased by 5.7% and 5.1% respectively.
Unscheduled Stops is found to be the most sensitive variable of the relationship with on-time performance. Each additional stop added to the unit of a route on-time performance decreases by -30%. This highlights the need for the provision of nonstop for buses. Skipping stop reduces delay experience by buses hence it acts to improve travel time reliability.

Scheduled stop is the next most sensitive explanatory variable in relation to on-time performance. The addition of one stop in a route section will increase on-time performance by 23.6%. This suggests that wider stop spacing will act to improve travel time reliability. Strategies like consolidating bus stops, back-door only for alighting, front-door only for boarding and low floor buses that shorten the boarding and alighting time can be of value to improve travel time reliability by reducing dwell time delays associated with bus stops.
Departure delay is found significantly associated with on-time performance. One additional minute of late running per unit trip decreases on-time performance by -9.2%. Clearly, a stricter management of on-time performance can act to improve scheduling adherence, and also improve travel time reliability.
In addition, all variables in the delay model follow in terms of statistical significance, exceptional PMPeak variable. *Direction* is the most sensitive variable in relation to bus delay. The results for direction coefficient suggest that delay indicator in an A-direction is 3.14 minutes less than that in B-direction. Morning peak service is the next in term of sensitivity of the relationship with bus delays. The addition of one minute in peak hours will increase delay by 0.94 minutes. On the other hand, evening peak service is not sensitive. The addition of one actual stop made will increase travel times by 0.506 minutes, almost 30 seconds. This is due to the absence of a number of passengers boarding the bus time variable in the data. Accordingly, the time associated to acceleration, deceleration, door opening, and door closing is included in the actual stop variables. For each unscheduled stop made will increase travel times by 1.114 minutes. If bus is delayed at the first stop by one minute, travel time is expected to increase by 0.633 minutes, while the delay at the first stop adds 38 seconds of run time for each arrival delay.
In our study, the models could be used in route planning purposes where different route alternatives are assessed. Clearly, there is much scope to improve the quality of this modelling by expanding the range of variables included.

7. Conclusions

This research used the bus route #51, stops and segments as case study, the findings of this research may be applied to any routes, stops and segments for the Tashkent context. The results from this research have applications both for research and practice.
For research, the knowledge of the GPS big data can be applied in better understanding bus travel time. This can be used in developing better route and stop designs to reduce travel time and delays. The concept of bus travel time could be applied to develop the scheduled and unscheduled stops for route. The first of the scheduled stop would provide the expected delay and arrival time of a bus at the destination. Whereas the second of the unscheduled stop would provide the congested time and area number for that individual bus trip. Such information should be provided to passengers in time to the actual arrivals for bus delays.
From the practical application prospective, the methodology for estimating travel time and delays at the bus stop or terminal can help transit planners for improving scheduling and travel time reliability. Since this methodology can be better incorporated in future, in the design of transportation service.
Overall this study provides a framework for collecting and analysing travel time data using GPS technology data. In addition, the statistical modelling alternatives used to establish a relationship between travel times and impact factors show that there is great potential to be able to study, with reasonable accuracy, travel time and delays.

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