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Causal analysis of bus travel time reliability in Birmingham, UK

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A R T I C L E I N F O

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A B S T R A C T

A reliable public transport system plays an important role in reducing energy consumption, carbon emission, road congestion and increasing urban operating efficiency. However, the reliability of public transport systems in some cities is facing the pressure of population and urban expansion, making it unattractive to passengers and leading to a higher level of car dependency. This paper focuses on Birmingham's bus service reliability and potential factors affecting bus travel delay based on the 63 bus route operational data in Birmingham. This study is conducted by doing data processing, bus travel time distribution analysis and, bus travel time delay causes analysis. For the analysis, models are developed by using Stata software. 12 variables are considered to estimate the bus delay. This study applies a regression technique to develop models. The results of bus travel time distribution analyses show the average bus travel time is behind schedule. The results of regression models show departure delay, number of signalised intersections, number of pedestrian crossing phases, and distance between stops are factors affecting bus travel delay. At the route level, the results show parades and roadworks could increase bus travel time delay while protests and rainfall have no significant effect and road accidents could sometimes impact bus travel time delay. Finally, it is recommended that a tighter bus on-time performance monitoring scheme should be applied to let drivers know the delay status of the bus and safely allow drivers to drive at a higher speed. Transit signal priority (TSP) techniques are also applicable but it needs detectors and traffic signals to be equipped on buses to give priority for buses at the intersection. Lastly, alternative diversion plans can also be provided in case of any predictable and unpredictable road closures. This is for being sent to passengers to assist passengers' decision-making.

1. Introduction

The public transport system, as one of critical infrastructures, is an integral part of city operation and city growth. A reliable public transport system plays an important role in reducing energy consumption, carbon emission, road congestion and increasing urban operating efficiency. However, the reliability of public transport systems in some cities is facing the pressure of population and urban expansion, making it unattractive to passengers and leading to a higher level of car dependency. A bus survey conducted by Birmingham City Council in 2019 shows that 73 % of passengers think Birmingham bus services are unreliable and do not plan to travel by bus any more [1]. Therefore, urban policymakers and transport agencies need to analyse and improve the reliability performance of bus services.

With the emergence of smart cities, information and communication technologies are widely applied in public transport systems, which makes it easy to access bus real-time operational data, including bus travel time and location information. The bus operational data is indispensable to analyse bus reliability performance, identify operation problems, understand problem causes, and form solutions.

The objectives of this study are 1) to understand the reliability performance of the 63 bus route in Birmingham, 2) analyse whether road attributes and general factors like parades and rainfall are contributors to bus travel time delay, and 3) form recommendations for reducing bus travel time delay and making bus services smarter, enabling Birmingham as a smart city.

2. Literature review

2.1. Bus service reliability in literature

2.1.1. Bus service reliability measures

Bus service reliability can be defined from different perspectives. From the user's perspective, high reliability means easy to reach bus

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stops [2], short waiting time at stops, and consistent journey time in daily service [3,4]. From the agency perspective, reliability is related to the invariability in the bus service performance [5]. Specifically, variation of travel time, variation of headway, travel time delay, and headway delay should be kept to a minimum [6]. These schedule-related delays can be seen as bus service quality indicators to some degree. Apart from those indicators, on-time performance is the main measure selected by transit agencies to monitor reliability performance. On-time performance is defined as the percentage of buses that finish a trip as scheduled [7], whereby this measure is preferred for bus services where the scheduled headways are longer than 10 minutes. Another measure for bus services where the headways are less than 10 minutes is the headway coefficient of variation. The headway coefficient of variation is defined as the standard deviation divided by the mean. This indicator is a direct measure of headway adherence and good headway adherence means improvement of service reliability.

2.1.2. Factors affecting bus travel time and reliability

A considerable number of studies on factors that affect bus travel time and reliability have been conducted. It is true that there are various factors affecting bus travel time and reliability, however, there are some basic factors that are widely agreed to have effects on bus travel time and reliability. Sterman and Schofer [8] identified that route length, intensity of intersection control, increasing traffic volumes, and bus passenger loadings affected the bus reliability. They also suggested several strategies to improve the bus reliability. Between stops, these factors could be traffic flow, distance, route type, departure delay, number of signalised intersections and so on [3,9]. At stops, factors could be passenger activity and lift use [10]. Other factors, such as weather, driver experience, time of day, bus vehicle type, and travel direction, have effects on bus travel time both between stops and at stops [11]. However, for each above factor, the estimated coefficients in the literature vary significantly. For example, El-Geneidy et al. [12] found that each additional intersection increases average bus travel time by 26 seconds, while the values found by McKnight et al. [13] and Albright and Figliozzi [14] were 11 and 10 seconds, respectively. The main reason for this phenomenon is that the studies were conducted based on different road characteristics and traffic conditions and various independent variables were selected in building the research models. Therefore, it is difficult to reach general conclusions about how these factors affect bus travel time and its reliability because of the variation in research background.

3. Data description and research methodology

3.1. Data description

The data used for this study contain both primary and secondary data. Secondary data refer to the 63 bus operational data, weather data, road incident record, roadworks record, and public events record. The 63 bus operational data were collected based on two free APIs. The Transport for West Midlands API [15] developed by the West Midlands company supplies real-time data and schedule data of all bus routes in Birmingham online. However, there are no historical data available in this API. Open Data Institute: Leeds designed the Real Journey Time API [16] which is used to store real-time information from the Transport for West Midlands API both real journey time and scheduled journey time are available in the Real Journey Time API. Real journey time is overwritten with the time that a bus departs from a stop and arrives at another selected stop. Scheduled journey time of any two selected stops refers to scheduled departure time minus scheduled arrival time. The data from the Real Journey Time API is only available since January 2019. All the bus operational data were collected using Python. The hourly weather condition data were collected from the Met Office website and the weather station at Coleshill which is 14.4 km from Birmingham. Compared with most other stations around Birmingham, this weather station captured the more comprehensive set of values. The records of a road incident and public event on the 63 bus route were collected from published news, company reports, government websites, relative Twitter messages, and Facebook messages from authority agencies like BBC News and Birmingham Live while roadworks data were collected from Birmingham City Council.

Primary data refers to road attributes of the 63 bus route including the number of pedestrian crossing phases and signalised intersections in each section and distance of each section. Specifically, there are two kinds of pedestrian crossing phases, signalised and unsignalised. A bus or vehicle is expected to stop at the unsignalised pedestrian crossing phase when there is a foot passenger waiting to cross the road and can move on once they have done so. While at the signalised pedestrian phase, a bus or vehicle must follow the signal light which means the driver cannot move on until the signal light changes even if the foot passenger has crossed the road. These two kinds of pedestrian crossing phases are believed to have different degrees of effect on bus travel time reliability. As for intersections, signalised roundabouts are considered as accounting. If there are two or more traffic lights on the roundabout that a bus must get through, then two or more intersections are accounted in this section. The distance of each section was measured by the author using Google Maps.

3.2. Research methodology

This research was divided into three sections, data processing, bus travel time distribution analysis, and bus travel time delay cause analysis. The 63 bus operated by National Express West Midlands departs from the city centre and finishes service at Arden Road Terminus (outbound) which contains 52 bus stops. There is a rural area at the end of the 63 route (outbound) which covers the final 13 bus stops and rarely has a bus service reliability problem because of low traffic flow and population density according to the statistic. Thus, these 13 bus stops were removed from research so the final data sample was limited to 37 stops (two more closed stops were removed). Before any analysis and modelling, the data need to be cleaned. The raw bus operational data ranges from 4:30 a.m. to 11:00 p.m. in April and May 2019 and the total number of records is about 150k (stop by stop level). As massive duplicate data were found in the early morning, this may have resulted from an abnormal location system, thus, the data generated before 5 a.m. were omitted. Other travel records containing negative values and null values were all deleted. Then, the difference between real bus travel time and scheduled bus travel time and the difference between real departure time and scheduled departure time were calculated. If the first difference was greater than 90 minutes at the route level (or 30 minutes at the stop by stop level) or the second difference greater than 60 minutes, the record was seen as invalid and removed. The final valid records are approximately 140k.

In the second section, bus travel time distribution analysis was conducted at the route level to have an overall understanding of the 63 bus travel time reliability performance. For each hour, there are about 3k bus operational records within the two months. So, the mean actual travel time and mean scheduled travel time can be calculated and compared to understand average reliability performance at different times of the day. Also, the mean actual travel time and mean schedule travel time of each hour can be calculated and compared.

To analyse the potential correlations between bus travel time delay and concerned factors, the analysis was designed into three levels and several regression models estimated in the last section. The referred levels are stop-by-stop level, route segment level, and route level. At the stop-by-stop level, a trip is identified between two consecutive stops and 37 stops, meaning there are 36 sections on the route. The 36 sections were named from *section 1* to *section 36* respectively. In each section, the road attributes are fixed while the actual departure time of each trip is random, meaning the data at the bus stop by stop level are panel data, having both *section name* and *actual departure time* dimensions. To check which factors affect the travel time delay, a random-effects model was estimated at the stop-by-stop level. However, the study at this level neglects to consider geographical and demographic effects as all the sections are put in the same condition wherein only considered road attributes factors are different. In fact, the 63 bus passes through the city centre area, university area, and suburb area, each having regional characteristics, so it is essential to analyse these areas respectively. For example, the number of signalised intersections in the suburb area may be independent of bus travel time delay, while it is possible that the bus travel time delay in the city centre area is related to the number of signalised intersections as there are higher population density and traffic flow. Thus, the 63 bus route is divided into three segments from the city centre to the final bus stop. Segment 1 relates to the city centre area and covers the first ten bus stops (nine sections), segment 2 relates to the university area and contains the following six sections which end at the 16th bus stop, and segment 3 starts at the 16th bus stop and ends at the 37th covering 21 sections. For each segment, a random-effects model was estimated. At the route level, a trip is determined when a bus departs from the city centre and stops at the 39th bus stop (Beverly Road stop, outbound) and there is a total of 3871 trips in the two-month period. To test the relationship between each event and travel time delay, a regression model between bus travel time delay and the five concerned factors was estimated.

In this study, all the models were calculated using Stata software and an alpha level of 0.05 was used, meaning the coefficients of variables are seen as significant only when the P values of these coefficients are less than 0.05. In addition, the aim of this study is to understand the relationship between bus travel time delay and concerned factors rather than explaining all the causes of bus travel time delay, thus, the R-squared values of the models are not deemed important. A description of the variables used in the models is presented in Table 1.

4. Bus travel time reliability analysis

4.1. Bus travel time distribution analysis

The mean actual bus travel time of the 63 outbound route is 46 minutes and 20 seconds while the mean scheduled bus travel time is 43 minutes and 26 minutes. This indicates that the average actual travel performance is 2.9 minutes later than scheduled. However, this deviation is not accurate enough to measure and understand bus travel reliability performance and it cannot offer more information about how bus travel time varies at different times of the day. Fig. 1 shows the distribution of bus travel time of the outbound route across the two months at different times of day (blue points). The mean actual travel time (red points) and mean scheduled travel time (yellow points) of each hour are also labelled. Accordingly, it is clear that the mean actual travel time of each hour is higher than the mean scheduled travel time, thus, it is acceptable to say that the trend of the 63 bus outbound service performance is to be late. From 5:00–6:00 a.m., the variation of travel time remains at a low degree as there are few passengers at bus stops and vehicles on the road in the early morning. From 6:00–12:00 p.m., the variation of travel time remains stable, ranging from 20 to 70 minutes. There is an expanding trend of variation from 1:00 p.m. until 4:00 p.m. because of interpeak and pm peak, and the travel time ranges from 28 minutes to 56 minutes after 6:00 p.m. An interesting phenomenon is that despite a pm peak, the variation between mean actual travel time and mean scheduled travel time is limited. The reason is that the schedule is flexible and the scheduled travel time is extended in the pm peak time by the schedule maker. Thus, transit agencies cannot improve schedule reliability by just adding more slack time to bus timetables because the bus speed will be slower and the trip time will be longer which increases users' time cost and transit agencies' operational cost [17], as well as undermines the sustainability of public transports [18–20]. Therefore, it is essential to analyse potential factors causing bus travel time unreliability.

Table 1
A slightly more complex table with a narrow caption.

	Description
Dependent variables	
Bus travel time delay	Actual bus travel time minus schedule bus travel time (seconds)
Independent variables	
SPCP	Number of signalised pedestrian crossing phase between consecutive bus stops
USPCP	Number of unsignalised pedestrian crossing phase between consecutive bus stops
SI	Number of signalised intersections between consecutive bus stops
SD	Section distance between consecutive bus stops (meters)
DDT	Departure delay time (seconds)
AM PEAK	1 if AM peak (5:00–9:30) and 0 otherwise
PM PEAK	1 if PM peak (15:30–18:00) and 0 otherwise
Parades	1 if there was a parade on the 63 bus route and 0 otherwise
Road accidents	1 if there was a road accident on the 63 bus route and 0 otherwise
Protests	1 if there was a protest on the 63 bus route and 0 otherwise
Roadworks	1 if there were roadworks on the 63 bus route and 0 otherwise
Rainfall	1 if there was rainfall on the 63 bus route and 0 otherwise

4.2. Modelling results

4.2.1. Stop-by-stop level regression model

In this section, a stop-by-stop model was estimated to analyse the potential relationship between bus travel delay in consecutive bus stops and road attributes. The road attributes variables are SPCP, USPCP, SI, and SD. In addition, departure delay time, am peak, and pm peak are considered in this model. The results are shown in Table 2. The coefficients of SPCP and USPCP are not significant indicating that the effects of the pedestrian crossing phase (signalised or unsignalised) on causing bus travel delay at stop level are negligible while the SI variable is significant and positive. This indicates that each additional signalised intersection between two bus stops increases bus travel time by 24.08 seconds. The SD is also significant and positive which means if the distance between two consecutive stops increases 1 m, bus travel time increases 0.13 seconds. The effect of departure delay is also significant and positive. Each second delay in departure increases travel time delay by 0.01 second. While the effects of am peak and pm peak are different, the pm peak variable is significant and positive because there are more passengers and congestion on outbound roads at that time. The result shows bus delay time increases by 13.64 seconds in pm peak hours.

4.2.2. Segment level regression model

In this section, the outbound route was divided into three segments and the travel delay time regression model of each segment is shown in

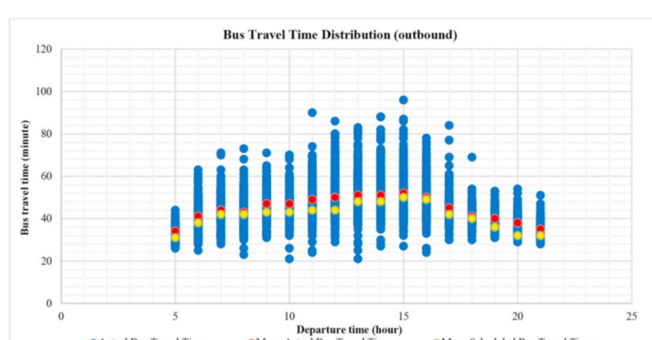

Fig. 1. Outbound route bus travel time distribution.

Table 2
Outbound stop-by-stop level bus travel time delay model.

Outbound sections	Bus travel time delay	
	Coeff.	p > |z|
SPCP	−1.20	0.798
USPCP	8.40	0.313
SI	24.08	0.011
SD	0.13	0.010
DDT	0.01	0.000
AM PEAK	−1.99	0.055
PM PEAK	13.64	0.000
N	59,357	

Table 3
Segment level bus travel time delay model.

Outbound	Bus travel time delay		Bus travel time delay		Bus travel time delay	
	Segment 1		Segment 2		Segment 3	
	Coeff.	p > |z|	Coeff.	p > |z|	Coeff.	p > |z|
SPCP	0.57	0.932	4.75	0.000	−4.86	0.629
USPCP	0	omitted	0	omitted	7.48	0.429
SI	22.54	0.144	41.98	0.000	19.46	0.173
SD	0.091	0.342	0.15	0.000	0.07	0.355
DDT	0.02	0.000	0.02	0.000	−0.001	0.304
AM PEAK	−8.28	0.000	4.61	0.030	1.46	0.219
PM PEAK	5.47	0.023	38.31	0.000	16.95	0.000
N	22,384		9077		32,279	

Table 3. For segment 1, only the departure delay time is significant and positive. The coefficient of departure delay time is 0.02 second which 0.01 second more than that of the stop-by-stop level. Other road attributes variables are not significant. In segment 2, all the variables are significant except USPCP. The effect of departure delay time in segment 2 is similar to that in segment 1. The coefficient of SPCP is 4.75 indicating that the travel delay time increases by 4.75 seconds for each additional signalised pedestrian crossing phase in the university area and each additional signalised intersection increases bus travel delay time by 41.98 seconds in the university area, about 19.44 seconds longer than in city centre area. As for section distance, each metre increase in section distance adds 0.15 seconds to bus travel delay. Furthermore, both am and pm peak time are estimated to have a significant effect on the travel time delay between each university area stop. Specifically, if the bus travels through the university area during pm peak time, the increased travel delay time is 38.31 seconds.

4.2.3. Route level regression model

As discussed above, the reliability performance of the 63 bus tends to be slightly behind schedule. Thus, two regression models are estimated to explain bus travel time delay at the route level. The dependent variable is the travel time delay which equals to actual travel time minus scheduled travel time and only positive values are considered. All the variables are measured in seconds. The results of the models are presented in Table 4. It can be seen that not all the variables are significant.

Table 4
Route level bus travel time delay model.

Valuable	Bus travel time delay (outbound)		Bus travel time delay (inbound)	
	Coeff.	p > |z|	Coeff.	p > |z|
Parades	−23.40	0.575	83.27	0.035
Road accidents	−182.65	0.005	−194.28	0.039
Protests	−61.84	0.687	94.63	0.151
Roadworks	82.15	0.000	123.12	0.000
Rainfall	50.46	0.106	39.03	0.123
N	2194		2509	

Parades variable is significant and positive in the inbound model but not significant in the outbound model. This means the parades conducted in the two months mainly had a negative impact on inbound bus operation performance. In both models, road accident variable is significant and negative indicating shorter bus travel time if there are more road accidents. The reason is the bus stop next to the accident scene is closed and the accidents in observations do not lead to road congestion. The protest in both models are not significant meaning that it is hard to say the protest is a reason to cause bus travel delay at the route level. However, roadworks in the two models are both significant and positive indicating that travel time will increase 82.15 and 123.12 seconds outbound and inbound respectively. Regarding weather effect, only rainy days are considered. Rainfall is not significant indicating rainy days rarely cause bus travel delay at the route level.

5. Conclusions

5.1. Summary of findings

This research focused on bus travel time based on the data collected along the 63 bus routes in Birmingham (mainly outbound). To understand the overall bus service performance, a bus travel time distribution analysis was conducted. It is clear that the mean actual bus travel time of each hour is slightly larger than the mean scheduled bus travel time indicating that there is a travel time delay problem along the outbound route. The peak of distribution occurred at 3:00 p.m. which coincides with the pm peak. It can be assumed that this is the time when schools finish. Parents and students travel using buses during that time. By implementing a flexible travel time schedule, the difference between mean actual bus travel time and mean scheduled bus travel time is not the largest at pm peak time because buses are allocated better to response demands at different times. Thus, it seems that making timetables more flexible is a direct and fast method to reduce bus travel delays for transit agencies. However, this needs to balance the operating cost and customer time cost which is very difficult.

To study the impacts of considered road attributes on the stop-to-stop travel time delay, a regression model at the stop-by-stop level using random-effects techniques was estimated. It shows that distance and number of signalised intersections between consecutive bus stops are factors increasing bus travel time delay while the number of signalised (unsignalised) pedestrian crossing phases are not. However, there is a defect in this model, as explained in Section 3. Thus, it is essential to combine the results of models at the segment level before any conclusion is made. At the segment level, it is clear that all three considered road attributes are factors affecting bus travel time delay in university area as the coefficients of these variables are significant in the model, whereas no relationship was found between concerned road attributes and travel time delay in suburb area and city centre area. Overall, number of signalised intersections, number of pedestrian crossing phases (signalised or unsignalised), and the distance between two consecutive stops all affect bus travel time delay. Furthermore, it is clear that the efficiency of signalised intersections in the university area should draw more attention to reduce travel time delay. Other approaches can be used such as removing signalised intersections in the university area because it can significantly improve the reliability while the traffic in the university area is not high until intersections are needed.

To study the effects of general factors like roadworks, protests, parades, road accidents, and rainfall on bus travel time delay, a route level regression model was estimated. Given the lack of bus travel data (only covering two months) and insufficient sample statistics, it is hard to obtain a powerful conclusion. However, there are still some valuable findings. Weather, roadworks, protests, parades or road accidents are, in essence, causes of road closure (or partial closure) which could result in bus service unreliability. The difference between these four factors is that road accident is unpredictable while the others are usually predictable. For predictable road closure, the key to reduce its effect on bus service is to plan an efficient diversion route while, for an unpredictable road closure, it is important to respond quickly and enable an alternative diversion plan. For rainfall, its effect on bus travel time delay is inconsequential.

5.2. Recommendations

Based on the results and discussion above, this study provides several recommendations for transit agencies and authorities to reduce bus travel time delay and make bus operation smarter.

First, a tighter bus on-time performance monitoring scheme is suggested to bus agencies. Specifically, setting several time checkpoints along the bus route (or at each bus stop) is suggested to let bus drivers know whether the bus departs late or not. If the bus departs late, the driver should drive the bus at a higher speed.

Second, the number of signalised intersections was found to have significant effects on a travel time delay, especially in the university area. This suggests the introduction of transit signal priority (TSP) techniques at main signalised intersections. To achieve this, buses are expected to be equipped with detectors and traffic signals should be upgraded so that buses can be detected at the intersection and given priority.

Third, transit agencies are expected to prepare alternative diversion plans for any route section to quickly respond to any predictable and unpredictable road closure. Any new road diversion information should be promptly sent to passengers by website or apps to assist passengers' decision-making.

5.3. Future research

The main limitation in this study is that this study only focuses on the situation when travel time is behind schedule. Travel times longer or shorter than timetabled actually represent both signs of unreliability. The reasons why bus travel time is shorter than timetabled are not included in this study. On this ground, timetable inconsistencies will be investigated in the future.

Author contributions

S.K., J.S. and S.H. conceived and designed the analyses and critical review criteria; S.K. and S.H. analyzed the data; S.H. and J.S. contributed materials/analysis advice and tools; S.K., J.S. and S.H. wrote the paper. All authors have read and agreed to the published version of the manuscript.

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Declaration of competing interest

The authors declare no conflict of interest.

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