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Development of Simulation Model to Improve Bus Service Reliability at High-Frequency Operation

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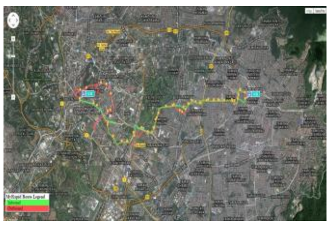
Graphical abstract



Abstract

The quality of service provided to passengers in high-frequency bus routes can be affected by variety of factors. According to this fact that high-frequency bus routes have high passenger demand and short headways (less than 10 minutes), interaction between buses would be much higher, causing decline in reliability of service. In order to represent a busy bus operation in Kuala Lumpur city centre network, a simulation model will be calibrated. The calibration and validation parameters for the key bus route will derive from data captured by the Automatic Vehicle Location (AVL) and Automatic Fare Collection (AFC) system and procedures will be outlined to adapt the model to other bus routes. The study is in its initial stage to find out what factors have highest impact on reliability of high-frequency bus services in the city centre. An initial model was developed for forecasting passenger demand by using RSM. The simulation model will first be used to conduct a sensitivity analysis of the factors influencing reliability, such as passenger demand, terminal departure behaviour, and unfilled trips. Next, several operating strategies, including terminal departure and time-point holding will be modelled and evaluated for their potential to improve reliability. Model results show that which strategies and factors can significantly improve bus service reliability.

Keywords: High-frequency; reliability; headway; simulation; automatic vehicle location; automatic fare collection

Abstrak

Kualiti perkhidmatan yang diberikan kepada penumpang di laluan bas berkekerapan tinggi boleh dipengaruhi oleh pelbagai faktor. Secara teori, laluan bas berkekerapan tinggi mempunyai permintaan penumpang yang tinggi dan masa kekerapan yang pendek (kurang daripada 10 minit), interaksi antara bas akan menjadi lebih tinggi, menyebabkan penurunan dalam keberkesanan perkhidmatan. Dalam usaha untuk mewakili operasi bas yang sibuk di rangkaian pusat bandar Kuala Lumpur, model simulasi akan ditentukur. Kalibrasi dan kesahihan parameter untuk laluan bas utama akan diambil dari data yang dirakam oleh sistem Lokasi Kenderaan Automatik (LKA) dan Koleksi Tambang Automatik (KTA) dan prosedur akan digunakan untuk menyesuaikan model bagi laluan bas lain. Kajian ini adalah di peringkat awal untuk mengetahui faktor yang memberi kesan kepada keberkesanan perkhidmatan bas berkekerapan tinggi di pusat bandar. Satu model awal dibangunkan untuk meramalkan permintaan penumpang dengan menggunakan RSM. Model simulasi terlebih dahulu akan digunakan untuk menjalankan analisis faktor sensitiviti yang mempengaruhi keberkesanan, seperti permintaan penumpang, tingkah laku berlepas terminal, dan perjalanan yang tidak dipenuhi. Seterusnya, beberapa strategi operasi, termasuk berlepas dari terminal dan masa-titik penantian akan dimodelkan dan dinilai bagi potensi mereka untuk meningkatkan keberkesanannya. Keputusan model menunjukkan strategi dan faktor ketara yang boleh meningkatkan keberkesanan perkhidmatan bas.

Kata kunci: Berkekerapan tinggi; keberkesanan; jarak kepala; simulasi; lokasi kenderaan automatic; kutipan tambang automatik

1.0 INTRODUCTION

In order to reduce the passenger load and waiting time in high frequency bus routes, the constant headways are considered as the best distribution approach, since the arrival of the passengers is assumed to be random.[1] On the other hand, the constant headways are not stable. As the matter of fact, the unpredictability of passenger demand, traffic and across operators, lead the bus services to an undesirable, stable of "bus bunching". The bus bunching refers to two or more buses which serving the same route in a tight schedule, within one minute typically.[2] Due to the high passenger demand, strong interactions are created between successive trips. So, the bus bunching is mainly common on high frequency routes.[3] The short headways and bus interactions result in unreliability propagation within high frequency bus route. Unreliability leads to growth in the crowd, waiting time and uncertainty in travel time increase, missed appointments and bus bunching.[4] The number of required vehicles, the standby driver's increasing operating costs and income loss caused by the reduced ridership of the transit agency are affected by the unreliable service on high frequency routes as well.

The passengers are inclined to arrive at the bus stops arbitrarily and to neglect the bus schedules, but the arrival of the bus at the scheduled headway is considered by the passengers on the high frequency bus routes in which the headways are not more than 10 minutes.[5] Consequently, the reliability of the high frequency bus route service is defined as the headway adherence at the bus stops in which a fixed route is served by a bus with a high frequency service. In order to develop a schedule for the high frequency bus routes, it is required to balance the costs between the passengers and the transit agency. The passengers are concerned about the shorter travelling and reliable waiting times. In order to balance the reliability and the travelling time, a clear scheduling process is needed by the transit planners.[6] The trade-offs between the total travel time and the reliability should be included in the mentioned scheduling process.

2.0 HIGH-FREQUENCY BUS RELIABILITY METRICS

2.1 Passenger Waiting Time

In order to specify the passenger waiting time on a high frequency bus route, a study on the behaviour of the passengers and the distribution of the headway is required. The estimated waiting time for the arrival of the next bus ought to be short in the worst case scenario of missing the bus.[7] The long waiting time is the result of the short scheduled headway and the bus arrivals variability. Thus, the reliability of the service depends on the regular headway schedule rather than the headway adherence from the passenger's point of view.[8] In Welding (1957) study, the passenger's average waiting time is used for the evaluation of the headway adherence impact on the passenger's waiting time.[9]

$$E(W) = \frac{E(H)}{2}\,(1 + Cov^2(H)) \quad (1)$$

E (W) in Eq. (1) stands for the average passenger waiting time at stops, the expected headway is shown by E (H) and Cov(H) refers to the headway's coefficient of variation. As it can be seen, the headway's coefficient of variation and the expected headway are the main factors for calculating the average passenger waiting time at the stops. Hypothetically, in case of fixed expected headway, an increase in the headway's coefficient of variation results in the increasing passenger waiting time at the stops. The average passenger waiting time is going to be the half of the expected headway, if the headway's coefficient of variation equals to zero.

2.2 Crowding Level

The quality of service for the on-board passengers will be reduced if the crowding levels amplify on the bus.[10] The passenger waiting time beyond headway will be higher in rigorously crowded buses. This is because the passengers couldn't board the first arriving bus. Based on the research, it is recommended to use the average crowding which the passenger experienced to measure the crowding rather than the average crowding for each vehicle on the route[4] (e.g. passengers are going to experience the crowding on a packed bus as twice as they experience the comfort of a half-full bus trip). The crowding level gained by the average passenger experience is more significant than the average crowding on the route. As it is shown in Table 1, the effect of crowding on the comfort in terms of different passenger loads on a 42 seat bus is defined as The Transit Capacity and Quality of Service Manual (TCQSM).[11]

Table 1 Crowding level categories

Load (pax)	Basis	Passenger Comfort	TCQSMLOS
21	0.5 ×(no. of seats)	Can sit next to unoccupied seat	A
32	0.75×(no. of seats)	Can choose seat	B
42	No. of seats	Seated	C
53	3.85 sq. ft. per standee	Standing but not crowded	D
62	2.2 sq. ft. per standee	Full	E
69	1.6 sq. ft. per standee	Borderline of crowded and overcrowded	F

The last column shows the level of service (LOS) associated with a passenger load up to the number. Regarding the authors of Transit Capacity and Quality of Service Manual (TCQSM), if there are 60 passengers on a 42 seat bus, 42 of the passengers are considered as seated (TCQSM LOS C), while the other 18 passengers are called standing and crowded, but it is not considered as overcrowded over crowded (TCQSM LOS E).

2.3 Schedule Adherence

The metrics of schedule adherence, which are implemented by transit agencies, are surveyed by the TCQSM.[11] The passenger's sensitivity to early departures on the bus routes with a low-frequency (in order to distinguish between high and low frequency bus routes, ten minutes headways are used.) is also discussed by TCQSM. As a result of passenger arrival behaviour and tendency of bus bunching, the headway regularity of the high–frequency routes is more vital than the schedule adherence as the manual explains.

The collected bus motion in these systems is not stable as it has been discussed before. It means that, the perfectly equivalent headways, consistently may become irregular, and the buses will bunch up if enough time passes. The reason of this instability is that, as a bus, which is followed by another bus encounters a disruption, it will run into a greater number of passengers along the way and this leads to further delay while the next bus inclined to catch up.[12] In order to solve this problem, a slack is added into the schedules by the transit agencies and time predefined control points toward the route are required for bus or other transit vehicle's departure.

3.0 BUS ROUTE SIMULATOR MODEL DESIGN

3.1 Input and Factors Influencing Variability

The four most important inputs needed for the simulation model and their variability influencing factors are defined and described here in this section. The mentioned factors are ought to be included in the data analysis and the development of the model as well.

3.1.1 Segment Running Time

The total amount of time (movement time in addition to dwell) between a key stop departure and the following key stop arrival is called the segment running time.[13] The minor stops serving time within a segment is not considered in the model, because the appropriate level of simulation model's detail used is the key stop. The segment's movement and minor dwell times are combined and a single time value is created. So, in order to predict the past time the departure key stop to the arrival of the next key stop regarding the influencing factors of the movement and the minor cumulative dwelling stop time, a model in needed.[14] The following is a list of the factors which have an impact on the segment movement and dwelling time:

1. The Number of Stops
2. The Traffic Signals (in terms of number and schedule)
3. The Traffic Interference
4. The Passenger's Activity
5. The Weather
6. The Operator Manners

3.1.2 Key Stop Dwell Time

The simulation model clearly represents the dwell time at each key stop. For each key stop, a model is needed for the estimation of dwell time anchored in significant influences such as the passenger's activity and the operator's manner as well. Here is the list of factors which affect the dwell time:

1. The Passengers Activity
2. Holding
3. The Operator Reliefs
4. The Location of the Stop.[15]

3.1.3 Terminal Recovery Time

Key stops are considered as terminals and they are modelled in an explicit way. The behaviour of terminal departure, which is a vital operation's control strategy and should be tested during the simulation model, model is needed. The terminal recovery time is affected by the factors which are listed below:

1. The Departure Policy
2. The Minimum Time
3. The Available Recovery Time
4. The Operator Behaviour, Training, and Policy Enforcement.[4]

3.1.4 Passenger Demand

The bus loading which is an essential metric in the definition of the model, includes the passenger demand distribution and the passenger demand rate. A model of time and location of passenger demand is needed for representation and calculation of the mentioned metric. In addition, the passenger perspective (i.e. the headway variation evaluation by the passengers) should be considered in an accurate measure of the bus service reliability.[16] The passenger demand will be affected by the factors listed below as well as the time and the location:
1. The Weather
2. The Time of Day

3.2 Outputs

The output of the simulation for each bus, key stop and each segment is represented in a text file which is separated by comma, and can be analysed by various applications such as spreadsheet viewers, statistical analysis applications and database applications. The route operations from a “bird’s-eye " point of view, is represented by a Graphical User Interface (GUI) in the simulation model in which the location, the schedule adherence and each bus passenger load are illustrated. Specific instructions such as speeding up and slowing down can be sending through the individual bus selection via the GUI.[17]

3.2.1 Visual Display

In order to debug the simulation model and to report to the user about the influencing reliability factor effects, the visual illustration is helpful. It is also useful in showing the route configuration, the location of the vehicle, the block identification, the schedule adherence and the passenger loading as it is designed to resemble a real-time AVL interface.[18]

3.2.2 Metric Collection

For route operation capturing, verifying and validating, passenger experienced waiting time and crowding for bus service reliability metrics and some other route operation details are required. Therefore, the collection method is sound, since the mentioned data will be used for model validation and all applications evaluation[7].

3.3 Model Setup

The key stops and segment information will be loaded and read from the configuration utility, by loading the simulation model. In addition, within the simulation environment, the road key stops and terminals will be loaded. During the initialization phase, merely the schedule blocks list will be loaded within the scheduler agent rather than bus agents.

3.4 Garage Pull-Out/Pull-In

The garage pull-out is incitement by the first block of time table. After that, a bus agent would be created by the scheduler and loads into the first stop of the first trip in the block. If there is any specific operator attributes can be added in the bus agent now. If operator specific attributes are used, they may be updated at each relief point in the bus block to reflect the change in operator. Simulation environment will remove the bus once it has reached the last bus stop on final trip in the time table block. If the run requires that a block not be filled, the scheduler agent will skip this step.

3.5 Serving a Key Stop

Once a bus stops at a key stop, data request will be sent to ground agent by the bus agent to receive necessary data including the dwell/holding time and passenger activity. The ground agent has the duty of calculation of passenger demand waiting to board and also calculation of the actual number of boarding passenger by considering bus capacity and alighting passengers. In case which the numbers of passengers were more than the bus capacity, the latest passengers to arrive at the stop (in case of passengers bypassed by multiple buses) are saved in a queue.[4]

Dwell time would be determined by using the passenger demand. If this stop involves an operator relief, trip recovery, or a service intervention then there may be a hold time that is longer than the passenger dwell time. If hold time is shorter that dwell time, the alighting passenger count is subtracted and the waiting passenger count is added to the on board passengers. On the other hand, if the hold time is longer than the dwell time, the alighting passengers are subtracted but the waiting passengers are not added at this time. While, only when the hold time has finished the waiting passengers would be added. This method ensures that passengers will board the first bus to depart from, rather than arrive at, the stop.

3.6 Terminal Recovery

Obviously, when the last stop of the trip is a key stop, the process will be exactly the same as serving any other key stop, with only one exception that all the passengers will alight and leave the bus at this stop and there will be no boarding passengers. After serving the last bus stop, the bus moves back to the first stop in order to start the next trip, or pulls back to the garage if this is the final trip of the block. According to terminal recovery strategies, the bus will take its recovery time, and then will start at the next trip. In this case, the available recovery time is calculated as the scheduled recovery time minus the schedule deviation.[7]

■4.0 RAPIDKL COMPANY ESTIMATED DATA

For reporting and analysis purposes, RapidKL uses the automatically collected data to estimate the route ridership per hour. This data can be used to predict the total route ridership to be distributed to each key stop (schedule time points and stops with high passenger demand) and segment in the simulation model.

4.1 Archived Data

The primary data source for model calibration is the raw automatically collected data from Automatic Vehicle Location (AVL) and Automatic Fare Collection (AFC) systems. The data from these systems is saved on the bus and transferred to the RapidKL database when the bus refuels.

4.2 Automatic Vehicle Location (AVL)

An AVL record is composed of the following: nearest stop location; bus, operator, trip, run and route identifiers; event, dwell and schedule adherence time information; and, if equipped with APC counters, passenger boarding and alighting per door and the number of on board passengers.

4.3 Automatic Fare Collection (AFC)

The AFC system creates a record for each fare transaction involving the smart media or magnetic stripe fare media: passengers paying with cash and non-paying passengers (e.g. children) are not recorded. Each record contains the event time, transaction type, fare box number and route number. The AFC data is a separate data collection system so the fare record is not automatically associated with an AVL record, although the system times are synchronized. The AFC data can be used in aggregate to estimate the total passenger demand at a finer time granularity than the hour interval of the RapidKL ridership estimates.

4.3 Data Collected from RapidKL Company

According to the agreement with RapidKL Company (Non-Disclosure Agreement), they have agreed to provide information, necessary and useful data to the SUTRA research group. After five meetings and discussions with RapidKL authorities, the selected route of U32 will be used as a typical high-frequency route to commence simulation model. After simulated and tested all factors on route U32, the simulated model will be expanded to other high-frequency routes. Table 2 and Figure 1 show a brief description of route U32 and the bus route (line) in Kuala Lumpur respectively. RapidKL Company also released the data on ridership and passenger demand of this route for three months (September, October and November 2014) together with buses time tables and list of buses with driver identifications. These data will be used in development of the simulation model.

Table 2 Route U32 details

Rout	Origin	Destination	Distance	No. of Buses	No. of Bus stops
U32	Taman Dagang	Bukit Bintang	20.565 Km	9	59

Figure 1 Route U32 Layout

■5.0 PASSENGER DEMAND MODEL

One of the most important components in a bus route simulation is passenger demand. The modelling of passenger demand will show how passenger demand on a route calculated considering time and location. Passenger demand directly effects on the dwell time and is a necessary factor to evaluate the service reliability. To evaluate the model, Response Surface Methodology (RSM) software was used. The multivariate methods such as response surface methodology (RSM) have been widely used for modeling of input effective variables to optimize the yield of the processes as output.[19-20] The model is produced by using semi-empirical data including experimental results, and a group of mathematical and statistical techniques.[21] Two factors considered to develop the model for estimating the passenger demand in route U32: time and location of bus stop. As mentioned before data collected for three months, but in order to develop this model data related to first week of November 2014, between 7:00 and 22:00 of route service was used. All data collected from RapidKL Company.

In the standard error limited region, the model of linear, 2FI, quadratic and cubic were compared by using Sequential model sum of square (SMSS).[22] The lack of fit test shows that the quadratic model presented minimum F-value and maximum P-value (Table 3). The ANOVA of the provisional model indicates the statistical evidence of the model and its terms (Table 4).

Table 3 summary results of SMSS

Source Remark	Sum of Squares	Degree of freedom	Mean Square	F-Value	p-value
Sequential Model Sum of Squares					
Mean vs Total	43838.08	1	43238.08		
Linear vs Mean	838.20	2	424.10	0.16	0.8670
2FI vs Linear	9.79	1	9.69	3.244E-003	0.9660
Quadratic vs 2FI (suggested)	26484.62	2	15342.31	57.16	<0.0001
Cubic vs Quadratic (Alaised)	1667.62	3	532.21	741.72	<0.0001
Residual	2.70	4	0.70		
Total	61681.00	13	5583.31		
Source Remark	**Sum of Squares**	**Degree of freedom**	**Mean Square**	**F-Value**	**p-value**
Lack of Fit Test					
Linear	28031.93	6	4508.65	6440.93	<0.0001
2FI	28052.24	5	5308.45	7926.35	<0.0001
Quadratic(Suggested)	1757.62	3	520.21	691.72	<0.0001
Cubic(Alaised)	0.000	0			
Pure Error	2.70	4	0.70		

Source Remark	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS
Model Summary Statistics					
Linear	43.01	0.0344	-0.1345	-0.8411	51371.30
2FI	54.82	0.0307	-0.2923	-3.0462	1.121E+005
Quadratic(Suggested)	14.93	0.9441	0.9041	0.5534	15529.57
Cubic(Alaised)	0.94	0.9999	0.9997		+

Table 4 The ANOVA of the provisional model

Source	Some of squares	Degree of freedom	Mean squares	F-value	P-value	suggestion
Model	1066.34	5	307.71	7.84	0.0101	Significant
X_1	176.27	1	176.27	6.08	0.0450	
X_2	1.16	1	1.16	0.051	0.8667	
X_1X_2	0.017	1	0.017	6.306E-004	0.9807	
X_1^2	253.07	1	253.07	10.53	0.0161	
X_2^2	822.34	1	822.34	29.27	0.0010	
Residual	194.76	7	27.82			
Lack of Fit	149.56	3	53.19	38.60	0.0013	Significant
Pure Error	4.20	4	1.30			
Cor Total	1338.31	12				
Std.Dev	R_{adj}	R_{pred}	R^2	PRESS	C.V %	Adeq Precision
5.27	0.6382	0.3768	0.7814	1490.63	29.71	9.343

The validated model for day, time and location (bus station number) of passenger demand for route U32 presented in Equation (1). This equation validated using data for three months and can be used to represent for weekdays only.

Passenger Demand = 11.5 – 1.6A – 1.88B + 3.00AB + 3.64 A^2 – 3.39B^2 (2)

Where, A is time and B is location of bus stops.

■6.0 FUTURE WORKS

So far, all the important factors which can affect the reliability of high-frequency service routes recognized and categorized. Also, all the strategies to improve the reliability of service determined and listed. All necessary data collected from RapidKL Company and also from site observation will be used. The next steps, several statistical tests and analysis would be done on collected data and pre-simulation models would be conducted such as: Segment Running Time Model, Key Stop Dwell Time Model, Terminal Departure Behaviour Model and Passenger Demand Model. All these models will be used in the next step which is developing simulation model. After preparation of simulation model, several validation and sensitive test will be conducted. The validated model will be used to determine the influence all important factor on reliability of high-frequency bus service and best strategies would be suggest to improve the service reliability of Route U32.

6.1 Model Verification and Validation

The most significant stages of the process of the simulation modelling are the verification and validation of the model. North and Macal[23] believe that "Before verification and validation, models are toys; after verification and validation, models are tools." Regarding the authors, assuring of the correctly calculated inputs and correctly programmed model is called the model verification. Conversely, the confirming process of the observed real world behaviour re-production by the model is known as validation.

6.2 Verification and Validation Application

The validation of the simulation will be during the route peak demand period, since at this period the operation approaches mostly affect the passenger and the running time variability, and passenger's demand magnitude is generally at its greatest scale. It means that, during the peak demand period, the effect of the poor service on the passengers is at its greatest level, so this phase is considered as the most challenging period to operate.[24]

On the other hand, the simulation of the trips during the peak period is not adequate, since the route's previous state of the will also impact the preliminary trips during the interest period. Therefore, the simulation of the immediately preceding to the peak time period trips, in addition to the peak time period is needed as well. Passenger's arrivals cannot be estimated by the headway at the simulation initialization, since the total trips are not populated and it results in an invalid headway.

Two statistical tests are used for the comparison between the results of the model and the route real observations. For the means comparison a two-sample, two-tail t-test is used while the two-sample F-test is employed for variance comparison. The mentioned tests are useful in the level of statistical significance in differences between the sample's measurements. The success measure will be the 5% level of significance which means that the means/variances are equal if there is not a significant statistical difference at a 95% confidence level in terms of means/variances

6.3 Sensitivity Analysis

In order to understand the reliability influencing factors, significance, a sensitivity analysis is needed. A parameter will be selected during the sensitivity analysis and a series of reasonable values will be removed through this parameter. For each parameter value, the number of twenty simulations will be performed. Passenger demand, the behaviour of the terminal departure (The accuracy and the minimum recovery time) and the filling trips percentage are included in the parameters which were selected for this analysis.

The passenger waiting time, the crowding and the huge gaps or bunching metrics are captured and compared during each parameter sweep. The passenger waiting time in both average and budgeted forms will be shown together with the comparison of the observation with the scheduled average and budgeted values of 3 and 5.7 minutes, respectively. The percentage of the passengers spending time at each crowding LOS group will be considered as the crowding. Seated passengers will be counted in crowding LOS A through C and standing passengers are counted in LOS D through F. For instance, a bus which is fully loaded includes only the LOS C passengers (seated passengers) and LOS F (standing passengers). The baseline results are also compared with the big gaps percentage and bunching. As the matter of fact that all schedule adherence issues (e.g. early arrivals at operator reliefs or late arrivals at the terminal) will be taken into consideration within the passenger centric metrics, the schedule adherence metrics are not considered here.

■7.0 CONCLUSIONS

A goal of the simulation model is that it can be readily adapted to other routes. The simulation model represents bus movement at the “key stop” (schedule time points and stops with high passenger activity) level of detail. The simulation model is constructed to be a research tool for testing a variety of preventative and corrective control strategies. The strategies that may be tested are limited by the available input data and the simulation model level of detail. Control strategies that could be effectively tested with this simulation model are, for example, preventative strategies that adjust the schedule and terminal departure behaviour as well as corrective strategies of holding, expressing, or short-turning buses.

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