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Design of Optimum Wait Time for Random Arrival of Passengers at Bus Stop: A Case Study from Putrajaya, Malaysia

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ABSTRACT

The waiting time can be reduced by providing information on bus arrival time. The absence of this information leads to long waiting time and affects passengers' planning travel time. Although the waiting period that is longer or shorter is subjective to each passenger, without information on bus arrival times, the uncertain passenger arrival time may cause difficulties to determine realistic waiting time. This study concentrates on the optimal design of the waiting time from the passengers' arrival time at random. The survey data were observed from one bus stop encoded as ALMD stop in Putrajaya. This stop has no mechanism for real bus arrival information, which raises issue of inconsistent bus arrival times to bus passengers. To analyze the problems, the combination of mathematics and response surface methodology-central composite design applications is used to design optimum waiting time. The design of arrival time was set up into two interval minutes: between 0–29 and 30–59 minutes, which was considered as the random arrival time of passengers. The modification on intervals for waiting time was designed between 0 and 15 minutes to meet the criteria of headway, one bus within 30 minutes. The design outputs resulted in a mathematical model for waiting time and optimization value. The results generated an optimum waiting time of 8.7 minutes for the first passenger and 13.81 minutes for the next passenger, which were the best times with respect to the bus operation headway.

Keywords: Bus passengers, design wait time, random arrival time, response surface methodology-central composite design (rsm-ccd), stop

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INTRODUCTION

Problems in waiting time arise when lack of information on scheduled bus arrival times and does not match accurately with the actual arrival times of buses. Furthermore, some stops have no information on real arrival times of the bus, which would cause waiting time become more longer. Real-time bus arrival information is very important to the passengers because they can arrange to use their waiting time more fruitfully to choose or to select an alternative mode of transportation. The passenger is more satisfied if the unpredictable waiting time is reduced; therefore, bus ridership also increases (Mishalani et al., 2006). It has conclusively been shown that the major factor in behavioral purpose of users to use public transport is related to service quality (Borhan et al., 2014). Ben-Akiva and Morikawa (2002) trace without information of the availability for the bus, waiting time for the next bus is highly uncertain. Without information on expected arrival times, it could cause anxiety (Yu et al., 2012) and lead to a negative perception among passengers assuming that there was no bus.

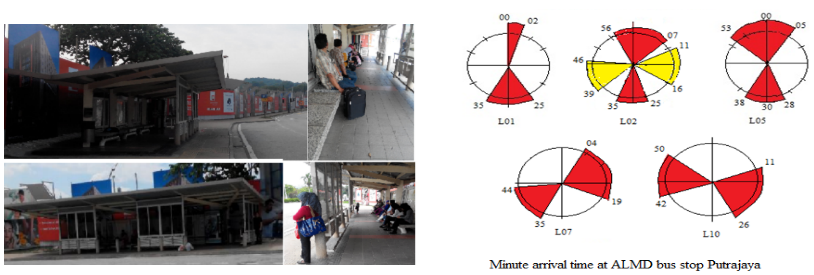
The duration of the waiting time is related to the delay in the departure of a bus from its origin based on a headway, the delay at bus stops during alighting and boarding of passengers, the process of acceleration and decelaration of a bus, queuing for a turn at stops, dwell time at stops, traffic lights and intersections, and being caught in the traffic or changing of bus speeds until it reaches its destination. The delay process involves three main stops: deceleration of bus, delay while opening doors, and alighting and boarding of passengers and the acceleration of the bus after departing from stop (Chen et al., 2013). Bus delay at a stop resulted from waiting for entry; departure of the front bus and green light is the average waiting time (Huo et al., 2015). Waiting time or delays play a critical role in the bus services. It is very precious and valuable. The value of waiting time is estimated to be half of a provided headway (Chang & Schonfeld, 1991; Chien & Qin, 2004; Furth & Muller, 2006; Wardman, 2001). According to Mohring et al. (1987), passenger waiting time is two to three times more than the transit time. According to the previous investigation, the value of waiting time is US$10/h/passenger (Chang & Schonfeld, 1991; Chien et al., 2003 - study case three cities in United States), RMB 2.7/h/passenger (Yu & Yang, 2009), 26 yen/min (Shimamoto & Schmöcker, 2012), and €51.29/bus (Ibeas et al., 2010 - study area in Santander, Spain). The actual arrival times from a bus information system have reduced waiting time to 0.7 minutes or 13% (Watkins et al., 2011).

There are many previous researches to reduce waiting time and is a significant model with a headway or bus frequency (Berrebi et al., 2015; Furth & Muller, 2006), household income (Mohring et al., 1987), total in-vehicle travel time and total operating cost (Liu et al., 2013), passenger crowding and effect on waiting time (Tirachini et al., 2013), partway deadheading operation optimization (Yu et al., 2012), overall delay a bus experiences at a stop (Huo et al., 2015), and social costs (Wagale et al., 2013). A relationship between a real-time information studied by Cats and Loutos (2016) yield that a predict waiting time is more closer to the actual waiting time compared with the timetable. Meanwhile, Wu et al. (2015) considered timetabling problem with stochastic travel times to minimize waiting time. Although while some researches have been carried out on waiting time, unfortunately very few studies have been carried out on design of the waiting time. This article will focus on the design of the waiting time for the random arrival time of passengers and buses at stops in Putrajaya. This issue was raised as a result of claims by passengers regarding the inconsistent bus arrival times at bus stops. The waiting time at the stops will be examined to find out whether the standards meet the limits and will be analyzed based on observations of actual data. This study also determined the length of waiting time caused, no information on actual arrival time, and vulnerabilities in the operating system or even the perception of bus passengers alone.

MATERIALS AND METHODS

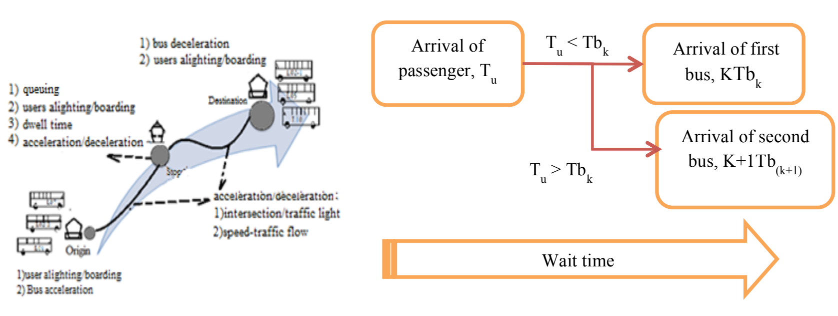
Concept and Framework Design

The study was investigated in a bus stop, coded as ALMD in Putrajaya, which has an average of 77 passengers per hour. It is the most popular stop for various routes because it is a transit or major stop to the business area. This stop had no facility of support vector machines for information on bus arrivals. Observations and collecting data conducted on-site using the scheduled time series were carried out randomly at off-peak time bus operation for 28 hours. Bus arrival times were observed and compared with the scheduled bus arrival times to elicit the waiting time. An interval of 30 minutes was set up on the first round and the second bus round, which was differentiated by the intervals, from 0 to 29th minute and the next 30th to 59th minute.



(a) (b)

Figure 1. (a) The ALMD Stop in Putrajaya; and (b) A Sketch on up-to-the-minute arrival information



(a) (b)

Figure 2. (a) Location of bus delays; and (b) Flowchart of passenger arrival time at random
Note: Tu, arrival time of passenger; Tbk, arrival time of first bus; and Tb(k+1), arrival time of second bus

Figure 1 shows the picture of ALMD stop and the result of observations presented in minutes upon actual bus arrival for each route. The main factor of expected delay was found during observations of arrival time routine at the stops. The flowchart in Figure 2 shows the all delays due to the bus operation and flow or design process of passenger arrivals at random for the bus. The criteria of constraint involved two main factors such as the arrival of passengers at the station and the arrival of the bus. The average interval between the arrival time of the first bus and the next bus refers to a headway, one bus within 30 minutes, if the arrival time of the passenger is equal to or less than the arrival time of the first bus, then the waiting time is not long. However, if the passengers missed the first bus, they have to wait for the second bus.

In this case, the passengers are divided into two categories that is passengers who arrive within the first 30 minutes (0–29th minute) and passengers who arrive in the next 30 minutes (30th–59th minute). The calculation of the waiting time is as shown in the following equations 1–3. If,

$$T_u \leq Tb_k \rightarrow T_m = Tb_k, - T_u \qquad [1]$$

$$Tb_k < T_u \leq Tb_{(k+1)} \rightarrow T_m = Tb_{k,+1} - T_u \qquad [2]$$

$$T_u \geq Tb_{(k+1)} \rightarrow T_m = 60 - Tb_{(k+1)} + Tb_k \qquad [3]$$

Response Surface Methodology-Central Composite Design. This study used a design expert response surface methodology-central composite design (RSM-CCD) to design a model passenger waiting time. RSM-CCD is used to model and generate a desired optimum value. There were several steps that had to be investigated especially in terms of criteria constraints so that problems that emerged could be solved accordingly in the study. The design was only for one stop (ALMD stop) and one route (off-peak hours) and categorized into two range periods referred to a bus headway (30 minutes). The proposed design was solely from the RSM-CCD with 54 experiments.

RESULTS AND DISCUSSION

The results of this design used real data of bus arrival times at ALMD stop, and the results are only suitable for one route off-peak hour (L01) in Putrajaya or any route that has the same criteria.

Waiting time design

The design summarizes the variables of factors A, B, C, D and responses Y1 and Y2 with their constraint values. Factor A is coded as TAP1 (arrival time of the first passenger), which is set in the arrival time in the range of minute 0 to the maximum minute 29, and factor B is coded as TAP2 (arrival time of the next/second passenger), which is set in the arrival time between the minimum minute 30 and the maximum minute 59. The factors C and D for the arrival time of the first and the next/second bus coded as TABL01-K and TABL01-K+n, respectively, use the real observe data that first bus arrives between minute 0 and minute 2 and the next bus arrives in the range of minute 25–35. After that, the wait time of first and second passengers (Y1 and Y2) is keyed in according to the 54^{th} experiment design with the waiting time from 0 to 33 minutes.

Analysis of variance (ANOVA) RSM-CCD

The development of model waiting time is given in Table 1, which has presented *F* value of 19.013 for the first passenger and 14.815 for the second passenger. This shows that the model is significant. 0.01% *F* value is limited to permissible errors. Therefore, the value "Prob > F," which is less than 0.05, shows that the model can be accepted. For this study, it was found that a significant model has a smaller value of 0.1000 while the larger more than 0.1 was the opposite. Criteria for the insignificant model would be disposed to improve the model. The determination of coefficient R^2 is useful when the ratio of the variance as a variable can be expected from other variables, namely that –x-axis and y-axis values can be expected. A strong relationship between the two variants can be specified with the following. The model is fit or most appropriate when its R^2 is equal to one. For example, correlated x and y in this study stated the analysis of three types of *R* squared: R^2, adjusted R^2, and predict R^2. The case study for random arrival time of passengers using time series data collection was very complex and difficult. Thus the value of R^2 predictions is emphasized and in reasonable agreement. The R^2 predictive model waiting time of the first and second passengers was 76.7% and 68.2%, respectively. Although the value mentioned was less than the actual R^2 value of 87.2% and 84.2%, it gave the best results for the model in this study in terms of the extent to which the model was able to predict new observations. In statistics, it was able to verify the prediction model in the study. Anyway if the values of predict R^2 and adjusted R^2 were less than 50% or get negative value, it is recommended to reduce too many input variables or increase a parameter data sample size. In addition of model prediction evaluation, RSM-CCD also generates value of adequate precision or simplified as Adeq Precision (AP). AP measures the signal-to-noise ratio. A ratio greater than 4 is desirable and showed the model in terms of its accuracy and appropriateness. The AP ratio for models TWP1 and TWP2, respectively, is 15.3 and 14.5 and indicates an adequate signal. ANOVA results indicated that the model is selected for passenger waiting time and the most significant use of a quadratic model.

The result forecasting for the first and second passenger waiting time quadratic model (first passenger represents first headway and second passenger represents next or second headway) was presented by RSM-CCD in the form of coded equations 1 and 2 as follows:

$$TWP1 = 13.72228 + 8(A) + 0.6667(C) - 5.222(D) - 11.8333(A)^2 + 2.6667(B)^2 + 2.667(C)^2 + 2.6667(D)^2 - 0.25(A)(C) - 6.5(A)(D) - 0.25(C)(D) \quad [1]$$

$$TWP2 = 14.5556 + 0.759(A) - 7.75(B) + 1.52778(C) - 5.027778(D) + 2.916667(A)^2 - 12.58333(B)^2 + 2.916667(C)^2 + 2.916667(D)^2 - 0.84375(A)(B) + 0.84375(A)(C) + 0.84375(A)(D) - 0.59375(B)(C) + 5.65625(B)(D) + 0.59375(C)(D) \quad [2]$$

TWP1, model of waiting time of the first passenger for route L01.

TWP2, model of waiting time of the second passenger for route L01.

A, up-to-the-minute arrival of the first passenger at stop in the first 30 minutes (0–29th minute).

B, up-to-the-minute arrival of the second passenger at stop in the second 30 minutes (30th–59th minute).

C, up-to-the-minute arrival of bus L01 at stop in the first 30 minutes (0–29th minute).

D, up-to-the-minute arrival of bus L01 at stop in the second 30 minutes (30th–59th minute).

Numerical optimization using RSM-CCD

The criteria of the six variables; arrival time of passenger 1, arrival time of passenger 2, arrival time of first bus, arrival time of next bus, waiting time of passenger 1 and waiting time of passenger 2 were set up their goal, limitation lower and upper and the weights. After that the 10 solutions recommended for optimum value. RSM-CCD design expert suggested that the interval in accordance with the actual data of the waiting time at the ALMD stop, Putrajaya be between 0 and 33 minutes to produce an optimum passengers 1 and 2 waiting time, which is between 8 and 24 minutes and 5 and 22 minutes, respectively. However, the range criteria are modified to the passenger waiting time interval of 0 and 15 minutes according to the headway of one bus within 30 minutes. The results showed a comparison before and after optimization and modifications proposed in Table 1b after the modified interval waiting time. The optimum value of waiting time for passengers 1 and 2 was 7 to 14.5 minutes and 0 to 14.5 minutes, respectively.

Table 1
Analysis of variance and criteria of numerical optimization and comparison of waiting time before and after optimization

Response	Route L01	Sum of squares	DF	Mean square	F value	Prob > F
TWP1	Model	5420.777778	14	387.1984127	19.01324047	<0.0001
	Residual	794.2222222	39	20.36467236		
	Lack of fit	794.2222222	10	79.42222222		
	Pure error	0	29			
	Cor. total	6215	53			
	R-squared	0.872208814				
	Adj. *R*-squared	0.826335055				
	Pred. *R*-squared	0.766858125				
	Adeq. precision	15.29964421				

Table 1 *(continue)*

TWP2	Model	5144.243056	14	367.4459325	14.81549598	<0.0001
	Residual	967.2569444	39	24.80146011		
	Lack of fit	602.7569444	10	60.27569444	4.795597089	0.0004
	Pure error	364.5	29	12.56896552		
	Cor. total	6111.5	53			
	R-squared	0.841731663				
	Adj. *R*-squared	0.784917388				
	Pred. *R*-squared	0.682045622				
	Adeq. precision	14.49875436				
b) Comparison of wait time before and after optimization						
Criteria				Limit		
Factor	Code	Goal		Minimum	Maximum	
Arrival time of passenger 1 (minute 00–29)		TAP1	Is in range	0	29	
Arrival of passenger 2 (minute 30–59)		TAP2	Is in range	30	59	
Arrival time of first bus		TABL01-K	Is in range	0	2	
Arrival time of next bus		TABL01-K+1	Is in range	25	35	
Response Before optimization						
Wait time of passenger 1		TWP1	Is in range	0	33	
Wait time of passenger 2		TWP2	Is in range	0	32	
Wait time of passenger 1—adj		TWP1	Is in range	0	15	
Wait time of passenger 2—adj		TWP2	Is in range	0	15	
After optimization						
Wait time of passenger 1		TWP1		8–24 minutes		
Wait time of passenger 2		TWP2		5–22 minutes		
Wait time of passenger 1—adj		TWP3		7–14.5 minutes		
Wait time of passenger 2—adj		TWP4		0–14.5 minutes		

Optimisation of graph

The optimum graph view in this study was set up for optimum waiting time by comparing the passenger arrival time on the *x*-axis with the first and second bus arrival times on the y-axis. The results in Figure 3 show that the forecasted waiting time of the first passenger is 8.7 minutes. The contour line assembles within the interval of 0–7.25 minutes between the first bus and the second bus. This means that the passenger must reach at stop in the duration of the accumulation contour line. The contour line gathers at the end of x-axis between the minute 51.75 and the minute 59.00 for the second passenger who has to wait 13.81 minutes, either for the second bus or for the next bus.

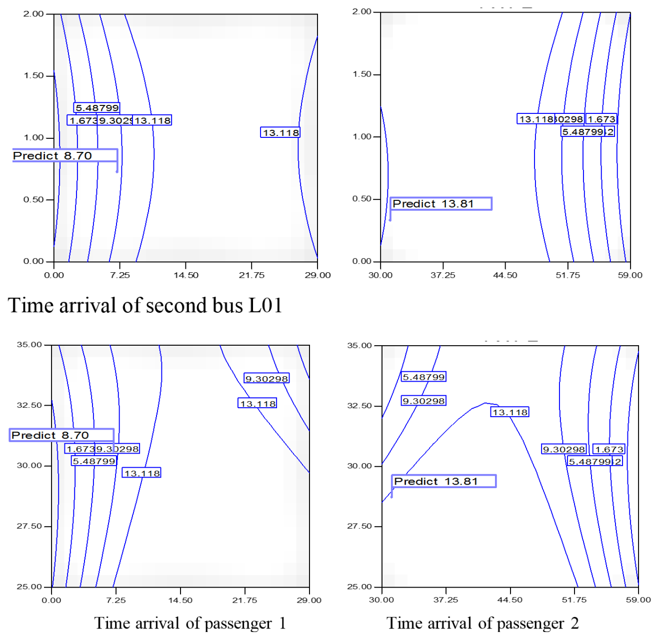


Figure 3. Optimisation of graph prediction waits time of passengers

CONCLUSION

This project was conducted to design waiting time especially to random arrival passengers at bus stop. These findings used real data from observations, a combination of design and application of mathematical models developed in accordance with the prevailing problems. The study of a waiting time based on the random arrival times of passengers and buses is very useful not only for new designs but also for existing designs. Analysis of the computed results shows the following:

- This research used four factors to design the optimization model: arrival time of the first passenger, arrival time of the second passenger, arrival time of the first bus, and arrival time of the next bus, and it also created two reponse optimization models: waiting time for the first passenger and waiting time for the second passenger.
- The evidence from this study suggests that the interval of the waiting time at the ALMD stop, Putrajaya, according to the criteria design 0 and 15 minutes, the optimum value of waiting time for the first passenger (first headway 00–29 minutes) was 7–14.5 minutes, meanwhile the next passenger (second headway 30–59 minutes) was 0–14.5 minutes. In addition to the aforementioned suggestions to overcome the situation, increasing headways is also recommended to minimize waiting time. Therefore, this study could be expanded with an integrated combination of application design or simulation algorithms or forecasted applications such as artificial neural networks and adaptive neuro fuzzy inference system to enhance the optimum value.

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REFERENCES

Ben-Akiva, M., & Morikawa, T. (2002). Comparing ridership attraction of rail and bus. *Transport Policy, 9*(2), 107-116.

Berrebi, S. J., Watkins, K. E., & Laval, J. A. (2015). A real-time bus dispatching policy to minimize passenger wait on a high frequency route. *Transportation Research Part B: Methodological*, 1-13.

Borhan, M. N., Syamsunur, D., Mohd Akhir, N., Mat Yazid, M. R., Ismail, A., & Rahmat, R. A. (2014). Predicting the use of public transportation: A case study from Putrajaya, Malaysia. *The Scientific World Journal*.

Cats, O., & Loutos, G. (2016). Real-time bus arrival information system: An empirical evaluation. *Journal of Intelligent Transportation Systems, 20*(2), 138-151.

Chang & Schonfeld, P. M. (1991). Multiple period optimization of bus transit systems. *Transportation Research Part B: Methodological, 25*(6), 453–478. doi:10.1016/0191-2615(91)90038.

Chen, S., Zhou, R., Zhou, Y., & Mao, B. (2013). Computation on bus delay at stops in Beijing through statistical analysis. *Mathematical Problems in Engineering*.

Chien, S. I., Dimitrijevic, B. V, Spasovic, L. N., 2003. Optimization of Bus Route Planning in Urban Commuter Networks. *Journal of Public Transportation*, 53–79.

Chien, S. I., & Qin, Z. (2004). Optimization of bus stop locations for improving transit accessibility. *Transportation Planning and Technology, 27*, 211-227.

Furth, P. G. & Muller, T. H. J. (2006). Service reliability and hidden waiting time – Insights from automatic vehicle location data. *Journal of the Transportation Research Board,* No. 1955, Transportation Research Board of the National Academies, Washington, D.C, (1955), 79–87.

Huo, Y., Li, W., Zhao, J., & Zhu, S. (2015). Modelling bus delay at bus stop. *Journal of Public Transportation*, 4142, 1-10.

Ibeas, Á., dell'Olio, L., Alonso, B., & Sainz, O. (2010). Optimizing bus stop spacing in urban areas. *Transportation Research Part E: Logistics and Transportation Review, 46*(3), 446-458.

Liu, Z., Yan, Y., Qu, X., & Zhang, Y. (2013). Bus stop-skipping scheme with random travel time. *Transportation Research Part C: Emerging Technologies, 35*, 46-56.

Mishalani, R., McCord, M., & Wirtz, J. (2006). Passenger wait time perceptions at bus stops: empirical results and impact on evaluating real-time bus arrival information. *Journal of Public Transportation, 9*(2), 89–106.

Mohring, H., Schroeter, J., Wiboonchutikula, P. (1987). The Values of Waiting Time, Travel Time, and a Seat on a Bus. *The RAND Journal of Economics*. Wiley, 18, 40–56.

Shimamoto, H., & Jan-Dirk Schmöcker, F. K. (2012). Optimisation of a bus network configuration and frequency considering the common lines problem. *Journal of Transportation Technologies,* 02(03), 220-229.

Tirachini, A., Hensher, D.A., & Rose, J.M. (2013). Crowding in public transport systems: Effects on users, operation and implications for the estimation of demand. *Transportation Research Part A: Policy and Practice,* 53, 36-52.

Wagale, M., Singh, A. P., Sarkar, A. K., & Arkatkar, S. (2013). Real-time optimal bus scheduling for a city using a DTR model. *Procedia – Social and Behavioral Sciences*, 104, 845-854.

Wardman, M. (2001). Public Transport Values of Time. Institute for Transport Studies, University of Leeds.

Watkins, K. E., Ferris, B., Borning, A., Rutherford, G. S., & Layton, D. (2011). Where Is My Bus? Impact of mobile real-time information on the perceived and actual wait time of transit riders. *Transportation Research Part A: Policy and Practice*, 45, 839–848.

Wu, Y., Tang, J., Yu, Y., & Pan, Z. (2015). A stochastic optimization model for transit network timetable design to mitigate the randomness of traveling time by adding slack time. *Transportation Research Part C: Emerging Technologies*, 52, 15-319.

Yu, B., & Yang, Z. (2009). A dynamic holding strategy in public transit systems with real-time information. *Applied Intelligence, 31*(1), 69-80.