Punctuality index and expected average waiting time of stage buses in mixed traffic

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Abstract

Long waiting times at bus stops and low occupancy of buses were the main problems suffered by bus users and bus operators, respectively. The objectives of this study were to analyze the punctuality of stage bus operation in mixed traffic, passenger's waiting time and to assess the characteristics of bus operation punctuality for various traffic and bus operation conditions. This paper presents the punctuality index and expected average waiting time of stage buses which were operated on a 82.6 km bus route with mixed traffic conditions. The historic GPS data from an on-board survey were used. The results showed that the average punctuality index was 0.29 and the expected average waiting time was 28 minutes at a bus stop or bus station. Based on the punctuality index, by referring to the Transit Capacity and Quality at Service Manual (TCQSM 2003) standard, the bus system service reliability was considered to have LOS B, meaning that vehicles are slightly off headway. The conclusion was that the service quality of stage buses in the mixed traffic can be evaluated based on the punctuality index and expected average waiting time by using on-board survey data.
Keywords: punctuality index, waiting time, stage bus, mixed traffic, on-board survey.

1 Introduction

Stage buses which are commonly operated in mixed traffic have many characteristics of operation which are influenced by various operating conditions and traffic circumstances. This bus system is provided on a route without a bus only lane facility, but it is operated sharing with other traffic. The bus is

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scheduled for connecting the start point (main bus station) to the end point (other main bus station), with a distance of 82.6 km in about 2 hours travel time. The bus could stop at any location along the route for passengers boarding and alighting.

The main problems of the current bus system are waiting times at bus stops and low occupancy of passengers. As the bus was mixed with other vehicles, therefore the reliability of the bus was relatively low and so that it could cause the bus system to not be attractive to travelers.

It is important to evaluate the punctuality index and expected average waiting time of the stage buses which were operated in a route with mixed traffic. Punctuality is often considered as one of the noticeable measures of bus operation reliability. It is used in evaluating bus operation performance from the point of view of bus users. Passenger waiting time is influenced by the punctuality of bus operation.

The purpose of this study is to analyze the punctuality of stage bus operation in mixed traffic, passenger's waiting time and to assess the characteristics of bus operation punctuality for various traffic and bus operation conditions.

Data for analysis were collected by field work (on-board survey) from the Ipoh-Lumut corridor. The data included route characteristics, number of passengers, number of vehicles, timetable and service frequency. Route characteristic was identified by means of handheld GPS. The sample was drawn for two typical days representing weekdays and weekends during period of one day (hourly), one week (daily) and one year (monthly). The analysis was performed to get the characteristic of punctuality and expected average waiting time. Punctuality of bus operation was discussed and characterized by various operating conditions.

2 Literature review

The level of service of a bus operation system from the viewpoint of users can be evaluated using various measures by qualitative factors that are not measurable. Reliability is one bus service level factor. Reliability is a very compound concept and can be described by several factors. For analyzing reliability, the punctuality and regularity are commonly used as the quantitative measures of reliability. Both are calculated by using the data of bus operations according to the scheduled and actual departure time [1, 2].

Passengers load factor and reliability that represent comfort and convenience can be appropriate for evaluating the level of service of bus operation systems. The reliability can be evaluated by the data collected about service frequency and the timetable (scheduled and actual departure). The passenger load factor requires the data collected by boarding and alighting of passenger during the operation period along the bus route [3, 4].

2.1 Reliability

Demand on public transport is highly affected by the public transport service level. Public transport service level is generally influenced by a number of factors, such as accessibility, waiting time, journey time, reliability, punctuality, fare, information and level of service [5–7].

As one of those factors, simply understanding the needs of reliability of public transport is about how reliable is the availability of the bus as per the scheduled departure time during service hours. Reliability includes regularity and punctuality of bus operation. Regularity can be defined as the percentage of intervals between actual trips that are within the acceptable interval at a location or a station during the service. Regularity is addressed to users' concerns about how long they have to wait from the time they arrive at the station until the departure time of the next bus [8]. High regularity means that bus users can ensure they get a bus service as well as it is scheduled. Meanwhile, punctuality is a measure of time gap between the actual and scheduled arrival time. Punctuality is related to headway adherence. Headway adherence, or evenness of interval, is the service reliability criterion that measures reliability much the way a customer would see it [9].

2.2 Punctuality index

Punctuality index, P_I, is an index indicating the magnitude of the time gap between actual arrival time and scheduled arrival time (adherence) as defined in Eq. (1) and Eq. (2) [10].

$$P_I = \frac{S_I^2}{h_t^2} \tag{1}$$

$$S_I^2 = \frac{1}{I}\sum_{i=1}^{I}(t_i - \tau_i)^2 \tag{2}$$

where h_t : Scheduled headways
I : Number of operations
t_i : Actual arrival time of i-th bus
τ_i : Scheduled arrival time of i-th bus
S_I : Standard deviation
P_I : Punctuality index

2.3 Method to determine LOS of headway adherence

According to the Transit Capacity and Quality at Service Manual (TCQSM) 2003 [11], the headway adherence is the time gap between actual arrival time and scheduled arrival time. The coefficient of variation of headway is calculated as shown in Eq. (3).

$$C_{vh} = \frac{\text{standard deviation of headway deviations}}{\text{mean scheduled headway}} \tag{3}$$

where C_{vh} : coefficient of variation of headways.

In TCQSM 2003, headway adherence is based on the coefficient of variation of headways, which can be related to the probability $P_I(|h_i - h| > 0.5h)$ that a given transit vehicle's headway will be off-headway by more than one-half the scheduled headway, and the Level of Service (LOS) is divided according to the linear increase of the probability $P_I\left(\left|h_i - h\right| > 0.5h\right)$. Headway deviations are measured as the actual headway minus scheduled headway. To classify the level of service of bus operation, it is necessary to refer to Table 1.

Table 1: Fixed-route headway adherence LOS.

LOS	C_{vh}	$P_I(\lvert h_i-h\rvert>0.5h)$	Factor $(1+P_I)$*	Comments
A	0.00-0.21	1%	<1.04	Service provided like clockwork
B	0.22-0.30	10%	1.05-1.09	Vehicles slightly off headway
C	0.31-0.39	20%	1.10-1.15	Vehicles often off headway
D	0.40-0.52	33%	1.16-1.27	Irregular headways, with some bunching
E	0.53-0.74	50%	1.28-1.55	Frequent bunching
F	>0.75	>50%	>1.55	Most vehicles bunched

Note: *The value of multiplier factor in calculating the expected waiting time.
Source: TCRP Report 100: TCQSM (2003) [11].

2.4 Passenger's expected waiting time

When passengers randomly arrive at the bus stop, the expected average waiting time of passengers is a function of the punctuality index. The punctuality index is a determining factor in calculating the expected average waiting time of passengers and is a statistically representative index to indicate the variation against the average. According to Chang and Hsu [6], Osuna and Newell [5], as cited by Park and Kho [12], the passenger's expected waiting time, *E(W),* is estimated using Eq. (4) and Eq. (5).

$$E(W) = \frac{\bar{h}}{2}\left[1 + \left(\frac{S}{\bar{h}}\right)^2\right] = \frac{\bar{h}}{2}\left(1 + P_I\right) \tag{4}$$

$$P_I = \left(\frac{S}{\bar{h}}\right)^2 = (C_{vh})^2 \tag{5}$$

where S : standard deviation of headway deviations.
$\bar{h}$: mean scheduled headway.
P_I : punctuality index.

If all vehicles run at an even headway, passenger's expected waiting time becomes a minimum value, i.e. half of the mean headway. Notice that the expression $(1+P_I)$ in Eq. (4) becomes a multiplier to the minimum expected waiting time, which increases as the standard deviation of headway deviations increases. The larger the P_I value is, the less regular the headway is (see Table 2) [10]. If all buses arrive at the bus stop on time, the punctuality index P_I is zero and the minimum value of expected average waiting time of passengers is obtained. If the distribution of bus arrival times is random, therefore the P_I will be a maximum, indicating the worst situation.

Table 2: Punctuality index and expected average waiting time of passengers.

Punctuality Index	Expected average waiting time of passengers	Arrival type
$P_I = 0$	$E(W) = \frac{1}{2}\bar{h}$ (Minimum waiting time)	All buses arrive on time
$P_I = 1$	$E(W) = \bar{h}$ (The worst case)	Complete random arrival

Source: Kho *et al* [10].

For convenience, it is suggested for the P_I to be converted into percentage value, ρ as in Eq. (6). Therefore, punctuality is high if buses arrive on-time.

$$\rho = \left[\textit{Percentage value of punctuality index } P_I \right] = \left(1 - P_I\right) \times 100 \tag{6}$$

3 Methodology

3.1 Case study: Ipoh-Lumut Corridor, Perak, Malaysia

The bus route of 82.6 km in length, within the Ipoh-Lumut corridor, located in Perak State, Malaysia was chosen for study. There are many new land use developments along this corridor. Ipoh-Lumut highway is being upgraded to be a key feature of the future road network in Perak. Ipoh-Lumut highway links Ipoh (State Regional Centre) and Lumut (State Sub Regional Centre). In addition, there are potential land uses in this corridor, such as universities, schools, residences, government buildings, public facilities, commercial and industrial areas, tourism facilities, etc.

The current bus service operates for 13 hours from 07:00–20:00 and is mixed with other traffic. During the operation period a driver of a bus can be stopped anywhere for passengers boarding and alighting. Problems faced by current bus services include limited facilities, low quality buses, inconvenient of fleets, low passenger trips, long waiting time and bad image of using bus services. The long waiting time for getting a bus is very common and it makes the system not attractive to users.

3.2 Data for analysis

The data represented the sample collected during a full one day service period (07:00–20:00), one week period (11:00–15:00) and one year period (11:00–15:00). The data used are primarily collected by an onboard survey on Perak Roadways' 14-hour weekday service, which is plying the Ipoh-Lumut corridor. The number of data points used for analysis was 12 months x 2 days per month x 2 trips per day or 48 trips per year. The primary data collected for analysis comprise the following:

a) arrival and departure times of the bus at stop points
b) location of stop points (bus station, bus stop and non bus stop)
c) name of location and environmental situation within the bus route.

In addition, secondary data were also used to help the surveyor on the primary data collection, such as road network map, timetable and other information on existing bus services.

3.3 Time-distance diagram

The time-distance diagram relates time and distance of bus operation. Figure 1 shows that the scheduled and actual departure times were not always the same, because there is a possible delay. The time-distance diagram is used as a guide for the bus operation time table. The current bus system starts operating from Ipoh (main bus station) at 07:00 to Lumut bus station and back at Ipoh at 20:00. The distance of 82.6 km is traveled three times a day during weekdays (Monday, Tuesday, Wednesday, Thursday and Friday) and four times a day during weekends (Saturday and Sunday).

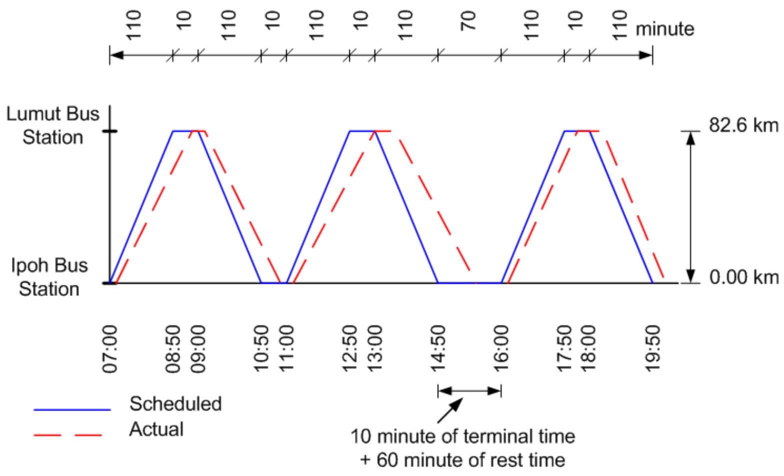

Figure 1: Time-distance diagram.

3.4 On-board survey (boarding and alighting)

The observer records the location and the time at which the bus stops for passengers boarding and alighting and also other data needed. Handheld GPS is used for recording the spatial and timely data. The observer also counts the number of passengers boarding and alighting over an entire route for a specified time period. The counts are used to determine maximum load points, variations in loads between buses, maximum loads, schedule adherence, bus speeds, destination and origin location, passenger kilometer, revenues, boarding passenger totals and system rider ship patterns.

Prior to analysis, the route was identified by using handheld GPS (Etrex LEGEND, Garmin). The points identified between two main bus stations (Ipoh and Lumut) indicated the place at which the passenger boarding and alighting. Figure 2 illustrates the on-board survey showing the location, distance, operating speed, travel time, and scheduled departure.

The observer situated inside the bus recorded the number of passengers boarding or alighting at stop points. At the same time, the observer also recorded or entered a code of the point into the handheld GPS at which passengers get on or get off the bus. This task was conducted repeatedly between the two terminals (start and end points) during the operating period. Since intercity buses have one door for passengers to get on or off, therefore only one observer was required and located near the door.

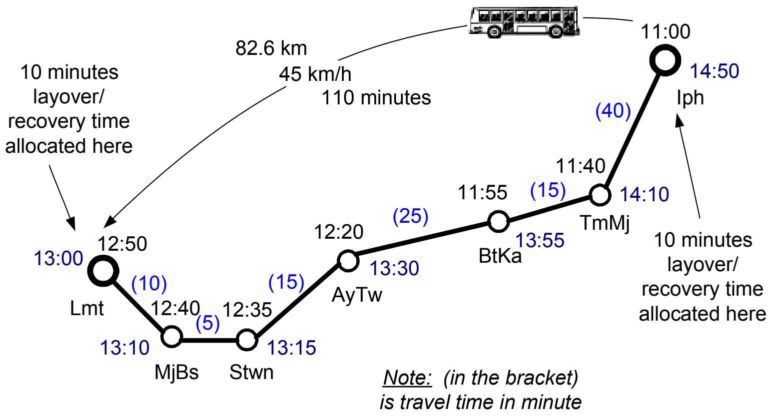

Figure 2: Location, distance, operating speed, travel time, and scheduled departure.

3.5 Method of analysis

From the data collected, analysis was performed and the following parameters were obtained:

(a) time-distance diagram for scheduled and actual departure,
(b) characteristics of bus service, such as route distance, travel time, operating speed, headway, frequency, cycle time, lost time, transport utility, number of bus (required, available, operated), availability ratio,
(c) comparison between the results and standard referred to.

By using the principles of the time-distance diagram, the analysis was performed to obtain the punctuality and expected average waiting time. The punctuality and expected average waiting time were then discussed with a number of characteristics of the bus service. The standard of TCQSM 2003, therefore, was used for guidance to evaluate the level of service based on these parameters.

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4 Results and discussion

4.1 Travel time

Various travel times of the round trip during 2007 are shown in Table 3 and Figure 3. By examining the travel time (T-test paired two samples for means, one-tail, 5% significant level) it is shown that there is no difference in travel time between weekdays and weekends. The value of 4.01 hours and 3.95 hours are statistically similar. The other fact is that the travel time slightly increased throughout the year. (See Figure 3).

Table 3: Travel time.

Month (2007)	Travel time (hour)		
	Weekday	Weekend	Average
Jan	4.13	4.12	4.13
Feb	3.92	3.70	3.81
Mar	4.32	3.58	3.95
Apr	4.15	4.07	4.11
May	3.90	3.80	3.85
Jun	3.80	3.95	3.88
Jul	3.95	4.13	4.04
Aug	3.97	3.97	3.97
Sep	3.97	4.18	4.08
Oct	3.78	3.95	3.87
Nov	4.07	3.90	3.98
Dec	4.13	4.08	4.11
Average	4.01	3.95	3.98

4.2 Operating speed and number of stopping

The percentages of stops among segments were varied according to the location and its length. In many segments, the number of stops per kilometer is less than one except for Sitiawan-Manjung bus station segment which registered 1.21 stops per kilometer.

Figure 4 shows the characteristics of the stage bus operation in mixed traffic identified by the various operating speeds and number of stops of the bus during boarding and alighting of passengers. Both the speed and number of stops are the main determining factors of stage bus operation in mixed traffic. The mode operating speed for both directions is between 36 and 40 km/h.

Figure 5 shows that the operating speed declined as well as the number of stops increased. The various operating speeds were identified to be influenced by the number of stops at which passengers get on and off. The gradient of operating speed for the Lumut–Ipoh direction was bigger than the Ipoh-Lumut direction. This is because the average number of stops in the Lumut-Ipoh direction is higher (30 stops) than those in the Ipoh-Lumut direction (29 stops). The average operating speeds for both the Ipoh-Lumut and Lumut-Ipoh directions are 43 km/hour and 40 km/hour, respectively.

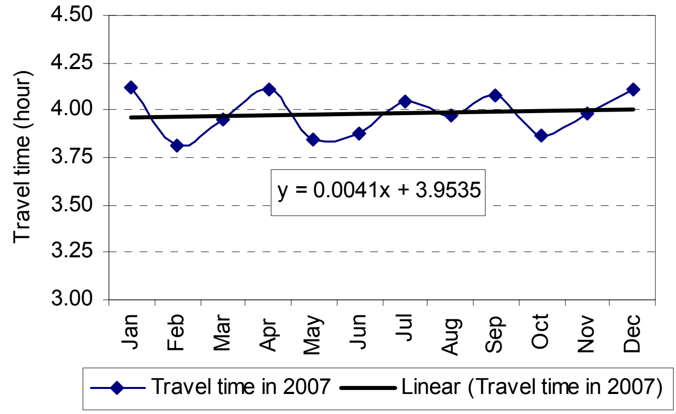

Figure 3: Travel time and its changes during year 2007.

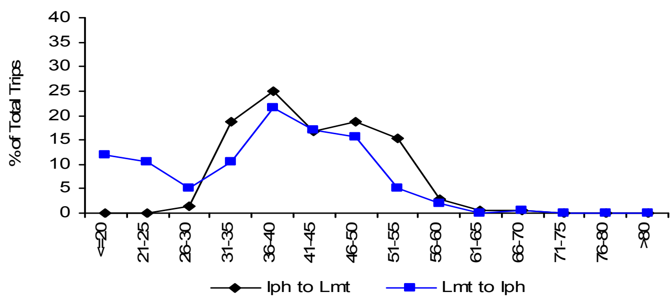

Figure 4: Distribution of operating speed along the route (overall weekday and weekend).

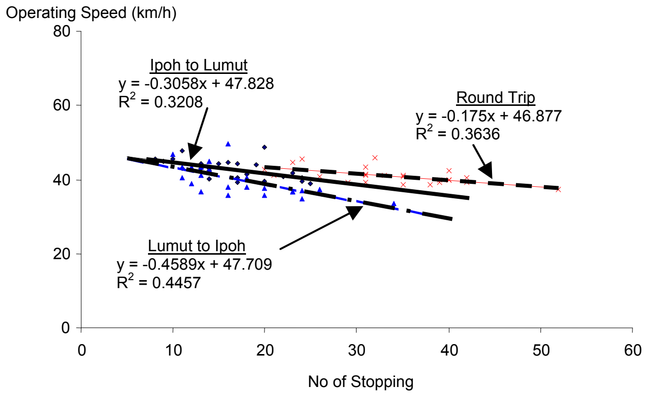

Figure 5: Relationship of operating speed and no. of stopping.

4.3 Service frequency and headway adherence

The existing bus was scheduled to operate with 30 minutes headway during the morning (07:00-10:00), midday (13:00-15:00), and evening (17:00-18:00 and 19:00-19:30) peak hour and with one hour headway during off-peak hour (10:00-13:00, 15:00-17:00, and 18:00-19:00). Based on the LOS threshold as recommended by TCQSM, this service was expected to operate at the LOS D during peak hour and LOS E during off-peak hour. Service frequency LOS D described that the bus service was unattractive to choice riders and LOS E means that the bus service was available during the hour. For instance, as the scheduled headway was 60 minutes, the frequency would be one bus per hour. Thus, the service was available during the hour.

Table 4: Headway adherence on typical day.

Location	Headway Adherence (minute)		
	Weekday	Weekend	Average
Bus stop	13.17	13.12	13.14
Ipoh bus station	23.67	19.75	21.71
Lumut bus station	16.25	16.92	16.58
Overall	17.70	16.60	17.14

Table 4, shows that the headway adherence of 23.67 minutes (weekday) at Ipoh bus station is the highest and it causes the average headway adherence to be highest. The high average headway adherence is also caused by many passengers, such as students going home from school during weekdays in the direction from Lumut to Ipoh. Figure 6 shows the statistics of headway adherence for all bus stops. The headway adherence was smoothly distributed with a skew to the left. It indicates that only about 48% of the buses arrived at the bus stops less than or equal to 10 minutes after the scheduled time. However, the distribution of headway adherence at Ipoh bus station shows that more than 87% of the buses arrived more than 10 minutes after the schedule. In other word, at Ipoh bus station, there was only 13% of the buses arrived within 0-10 minutes after the schedule. Meanwhile, for Lumut bus station, 38% of the buses arrived within 0-10 minutes after the schedule.

4.4 Punctuality and expected waiting time

The punctuality index of a bus route was calculated by averaging punctuality indexes at all bus stops in the route. For the extensive analysis, punctuality index of bus operation was distinguished by the location of bus stops and categorized in according to the typical days, weekday and weekend. The average punctuality index is 0.29 (the percentage of punctuality index, $\rho = 71\%$) with the minimum and maximum values at 0.07 and 0.61, respectively. Meanwhile, the expected average waiting time is 27.67 minutes with the minimum and maximum values at 19.00 and 34.60 minutes, respectively.

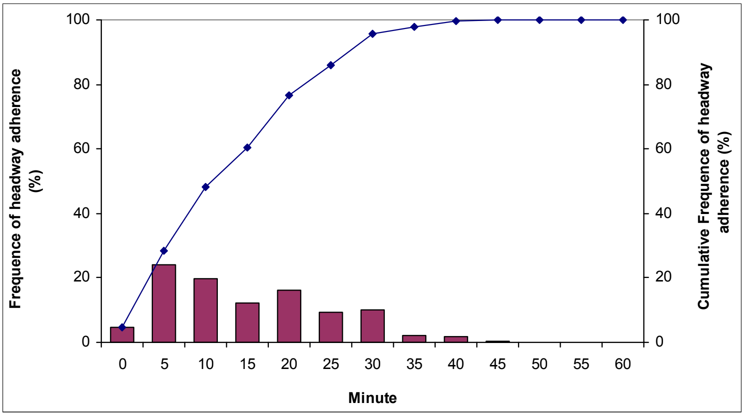

Figure 6: Cumulative frequency of headway adherence for all bus stops.

Punctuality indexes of bus operation at the bus stop or bus station can give an indication to passengers of the reliability of the bus service. The lower punctuality index indicates the shorter headway adherence. Based on the punctuality index obtained, and by referring to the TCQSM standard, the bus system service reliability is considered as LOS B, meaning that vehicles are slightly off headway.

The result of T-test (paired two samples for means, 5% significant level) shows that punctuality indexes of weekdays and weekends are not statistically different. The result was the same for the expected average waiting time. The t-statistic value was less than the t-critical one tail value for both punctuality index and average waiting time. This is because the average route travel time during weekday and weekend are not different, although the load factor of weekend (67%) was higher than weekday (51%).

5 Conclusion

From the data analysis above and by using an on-board survey method, several results were obtained. The conclusions that can be drawn are as follows:

1) The operational measures of bus service characteristics have been identified, such as trip utility of about 495.6 km per bus a day, average travel time of 3.98 hours per round trip, and service frequency of 1 and 2 buses per hour during off-peak and peak hours, respectively. By referring to the LOS threshold value of the service frequency in the TCQSM 2003 standard, the bus service was categorized to operate at the LOS D during peak hours and LOS E during off-peak hours. The bus service was unattractive to choice riders (LOS D) and was available during the hour (LOS E).
2) The reliability bus service can be evaluated based on the punctuality index. The result shows an average of the punctuality index of 0.29 and an expected average waiting time of 28 minutes. Based on the punctuality index, by referring to the TCQSM 2003 standard the bus system service

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reliability is considered to LOS B, meaning that vehicles are slightly off headway.

3) The punctuality index can be used to evaluate service quality of the stage bus operation in mixed traffic. The punctuality index can be used to determine the expected average waiting time. Based on the T-test result, the punctuality index during weekdays and weekends are not significantly different.

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