RESEARCH ARTICLE

A Comparison Between Conventional and High-Priority Bus Services in Davao City, Southern Philippines

Sherelyn A. Evangelio • Marie Analiz April A. Limpoco • May Anne E. Mata✉
University of the Philippines Mindanao, PHILIPPINES

Abstract

The increasing demand for transport system in Davao City has paved the way for the proposal of two transportation options, namely, the conventional bus service (CBS) and high-priority bus service (HPBS). A necessary step for transport policy making is quantitatively determining the differences between these transport options. In this study, we compare the projected performances of CBS and HPBS in terms of their expected load factor and passenger waiting time at chosen stations in Davao City. Our assessment is based on the data gathered about the existing public transport system at eight stations in the Mintal area during the morning rush hours. A single server batch service queueing model was adopted in this study to approximate the passenger waiting time at a station for each transport option. Passenger arrivals are fitted to a Poisson distribution using least square methods yielding a headway/service time of 3 min and service frequency during the observation period is 40. Our results show that though the load factor of CBS is higher than the HPBS, it fails to meet the passenger demands at some stations, which resulted in increased passenger waiting time. Our analysis points to HPBS having a better projected performance than CBS in terms of load factor and passenger waiting times at Mintal stations. The methods we developed can be used to perform similar studies for other stations or times, e.g., off-peak and evening rush hours, and provide new insights about these transport options.

Keywords: load factor • passenger waiting time • single server batch service queueing model

Correspondence: MAE Mata. Department of Mathematics, Physics, and Computer Science, College of Science and Mathematics, University of the Philippines Mindanao, Mintal, Tugbok District, Davao City 8022, Philippines. Telephone: +63 82 293 0302. Email: memata@up.edu.ph

Author Contribution: SAE and MAAAL conceptualized this research and designed the methodology. SAE gathered the data, formalized the analysis, and interpreted the results. SAE and MAAAL drafted the manuscript. MAEM evaluated the results and analysis, reviewed the manuscript, and supervised the writing process for journal submission. All authors gave final approval for publication.

Editor: Emma Ruth V. Bayogan, University of the Philippines Mindanao, Philippines

Received: 6 April 2017 **Accepted:** 12 October 2017 **Published:** 27 October 2017

Funding Source: Personally funded

Competing Interest: The authors have declared no competing interest exist.

Citation: Evangelio SA, Limpoco MAAA, Mata MAE. 2017. A comparison between conventional and high-priority bus services in Davao City, Southern Philippines. Banwa 12B: art009.

A Comparison Between Conventional and High-Priority Bus Services in Davao City, Southern Philippines

Sherelyn A. Evangelio • Marie Analiz April A. Limpoco • May Anne E. Mata✉
University of the Philippines Mindanao, PHILIPPINES

Introduction

A transport system is the means by which to move passengers or products from a source to a destination. It supports the accumulation and concentration of economic and social activities of urban areas, whose productivity is highly dependent on the efficiency of its transport system. As population increases and economy rises, the demand for transport system also increases, which generates challenges on its efficiency. In the Philippines, the common challenges include traffic congestion, longer commuting, and public transport inadequacy (Reyes 2012), which are spawned by the underdeveloped transport system of the country. These underline the need for a more effective public transport system. Hence, local governments are now turning their attention to addressing the issues concerning transportation (Zhao et al. 2005).

Due to its strong economic growth, Davao City experienced an increasing demand for transport, which led to issues on congestion, reliability, safety of operations, and governance of the city's transport system (Carillo 2013; Deligero 2013). The public transport system covers 80% of trips within Davao City and is predominated by jeepneys. Other public transport vehicles are vans, taxis, and motorized and nonmotorized tricycles. However, the regulations governing the public transport system are outdated. The city also lacks an effective transport masterplan, and the institutions managing transportation do not coordinate with one another in planning and the implementation of these plans (DSEB 2013).

In 2010, the Japan Fund for Poverty Reduction sponsored the US$1-million Davao Sustainable Urban Transport project (ADB 2013; Lumawag 2013), which aimed to attain a sustainable and effective public transport system in the city. The initial study conducted by a team of local and international consultants from Transport and Traffic Planners Inc. and Asia Halcrow Inc. recommended four public transportation options for Davao City: conventional bus services (CBS), highly prioritized bus services (HPBS), bus rapid transit (BRT), and light rail transit (LRT). However, BRT and LRT, which require 25-meter-wide roads, cannot operate on the existing 15-meter-wide roads of the city. Hence, the transport options for Davao City were reduced to CBS and HPBS. The main difference between the two is that CBS has a passenger capacity of 60 while HPBS has 90. These two transportation options are yet to be operational within Davao City, and their projected performance must be approximated based on the performance of the existing public transport system of the city.

The load factor and passenger waiting time are two measures that can be used to determine the projected feasibility and effectiveness of the proposed transport system. The load factor is a measure of capacity utilization, i.e., how much of a vehicle's passenger carrying capacity is used. It is expressed as the ratio of transport demand to supply (Mendoza and San Diego 2008) such that an increase in the load factor implies a more profitable operation. The passenger demand is defined as the average number of passengers for every route, while the supply is defined as the number of passenger seats when the frequency of the vehicle is multiplied to its seating capacity. The passenger waiting time, on the other hand, is defined as the time that elapsed from the moment a passenger arrived at the station until the passenger is served, and it can be estimated as a function of bus departure time intervals (Gong et al. 2013). Lesser waiting time implies a more effective transport system as found by Salek and Machemehl (1999) who developed a model for predicting bus passenger waiting times using experimental data. In this study, we assessed the projected performance of CBS and HPBS in terms of the load factor and passenger waiting time.

The expected passenger waiting time is traditionally determined using the half headway model (Fan and Machemehl 2002, 2009; Salek and Machemehl 1999). The model is based on three assumptions: (1) the arrival time of the passenger is random, (2) the passengers can get on the first vehicle that arrives, and (3) the vehicles arrive regularly. However, the third assumption is not satisfied in this study since we have a non-operational transport system and the necessary parameters, e.g., headway and frequency of the actual vehicle, are impossible to determine. Thus, there is a need to explore other methods to determine passenger waiting times.

A known method widely used to quantify waiting phenomenon is queueing theory—a branch of operations research that deals with the mathematical study of waiting lines or queues (Taha 2003). Queueing systems are defined by three elements: customers, servers, and queues. In a transport system, the passengers are the customers and the vehicle is the server. Here we represent the transport system as a single server batch service queueing system wherein customers (passengers) arrive individually or in bulk (group) and service (vehicle) is provided in batches (Ayyappan et al. 2013).

We compare the CBS and HPBS in terms of their projected load factors and passenger waiting times, wherein the latter is based on the single server batch service queueing model. To achieve this objective, we determined the desired waiting time of passengers at the different loading stations in the Mintal area. The jeepneys, vans, and buses are the considered public transportation vehicles as they have similar loading and unloading behaviors. We proposed a transport vehicle headway based on the desired waiting time of passengers at each station. Using this quantity, we computed the load factor and the expected passenger waiting time for each transport option per station. We highlight the use of single server batch service queue in analyzing the projected performance of a proposed public transport system.

The results of this study are useful for planning a sustainable transport system in Davao City. In addition to the efforts made for Davao Sustainable Transport project, this study helps in determining the feasibility of the proposed transport system in terms of its projected performance and can be presented for demonstration and replication in subcentral areas in Davao City such as Toril, Calinan, Tibungco, and others. This study contributes to the literature on public transport systems in the Philippines, a topic in which few studies have been conducted so far.

Methodology

Problem Description

Suppose that there are two processes involved in the arrival and departure of the passengers at the loading and unloading station. First, passengers arrive at the station by foot and depart through a public transport vehicle (e.g., jeepney, van, bus, or taxi). Second, passengers arrive at the station through a public transport vehicle and depart by foot. We assume that public transport vehicles load and unload passengers only at any of the eight stations in Mintal area (Figure 1), namely, Mintal Public Market (MPM), Panadero Bakeshop (PB), Holy Spirit Hospital (HSH), Relocation site (RS), Green Meadows Subdivision (GMS), Catalunan Crossing (CC), Pag-Ibig (P), and Ulas Crossing (UC) if their destinations are within the Mintal area. Stations beyond Ulas Crossing are no longer covered in this study.

Let us denote the arrival rates of passengers and vehicles at a station as λ and μ, respectively. When the vehicle arrives, it unloads a random number, $n \in [0, C]$, of passengers where C represents the maximum seating capacity of the vehicle. The vehicle then loads passengers from the station. If there is no passenger in the station, the vehicle proceeds to the next stations with at least one waiting passenger. Moreover, let k be the number of passengers that is tolerable for a vehicle to wait upon before it departs the station, i.e., k represents the fixed batch size. This means that if there are less than k passengers in the station, the vehicle waits until k passengers are loaded before it departs the station. The loading of passengers is on a first-come-first-served basis.

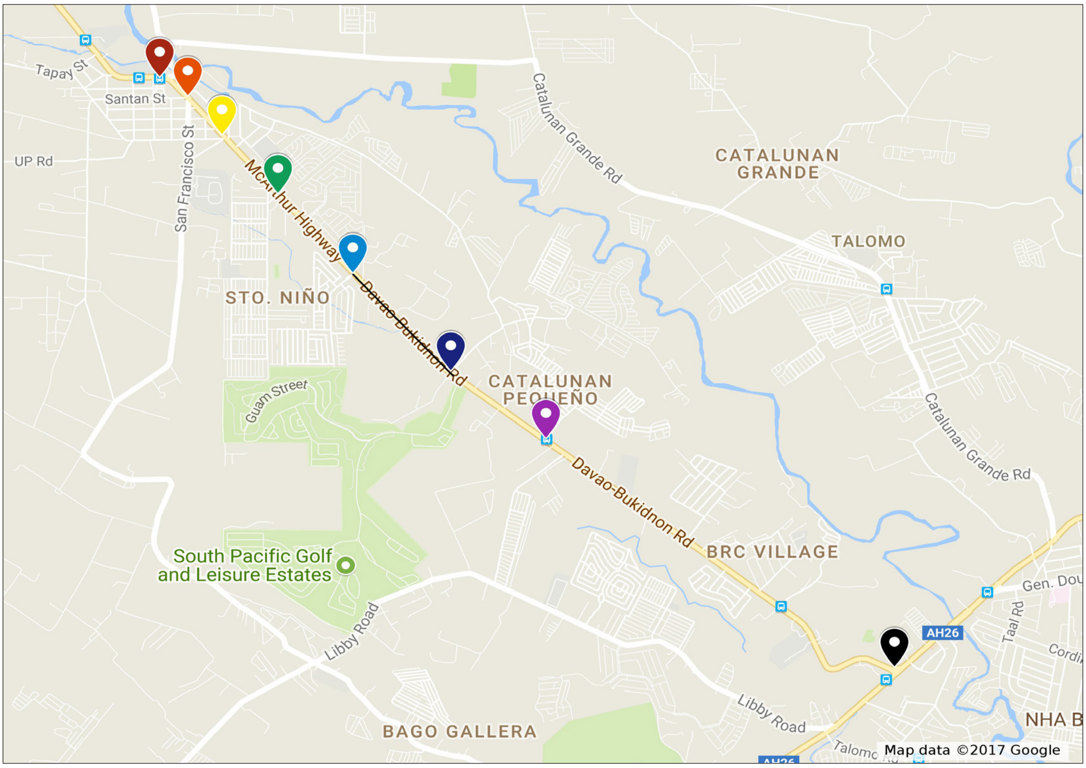

FIGURE 1 Map of the eight loading and unloading stations from Mintal Public Market to Ulas Crossing, Davao City

We introduce the Kendall notation (Martin 2004; Taha 2003) to describe, in a compact manner, the batch service queueing model of the transport system discussed above. The Kendall notation follows this format: $a/b/c$, where a is the arrival distribution, b is the departure (service time) distribution, and c is the number of parallel servers. Since the arrival (or departure) of the passenger at the station is a Markov process where future number of arrivals depend on the current number of arrivals, the transport system can be approximated by the $M/M^k/1$ model where M represents Markovian arrivals distribution and M^k denotes Markovian departure distribution with batch size k. In this study, k is considered as the expected number of passenger arrival in the stations.

Data Gathering

We consider the eight loading and unloading stations from Mintal Public Market to Ulas Crossing in Davao City. The data were collected between 6:30 and 8:30 AM, which encompasses the morning rush hour, on weekdays. Passengers travelling by means of taxi were not included in the data collection since taxis have no definite loading schemes. Data collection was divided into two parts: the survey and the cross-sectional observation. First, the desired waiting time of the passengers were determined for each station through survey. Second, the number of passengers that arrive at the station to wait for a ride (P_{arrive}) and (2) number of passengers that are unloaded at the station via jeepney, van, or bus (P_{unload}) were collected for every one-minute interval. No data were collected on Saturdays and Sundays since the travelling behavior of the passengers differ significantly on these days compared to weekdays.

Estimating the Expected Number of Arrivals

We fit the observed passenger arrival per minute at each station to the Poisson distribution using ordinary least square method (Abdi 2007; Bluman 2012; Lowry 2013) and estimate the expected number of arrivals λ based on the minimum sum of squared errors (SSE) between observed and Poisson expected frequencies. For a Poisson random variable X, the probability of observing x arrivals in a given interval is known (Hillier and Lieberman 2001) and can be expressed as follows:

$$P(X = x) = \frac{\lambda^x e^{-\lambda}}{x!}, \quad x \in Z^+ \tag{1}$$

Applying Equation 1 to the standard formula of SSE (Abdi, 2007), the SSE of the Poisson distribution is given by the following:

$$\text{SSE} = \sum_{j=0}^{10} \left(f_j - n \frac{\lambda_i^{x_j} e^{-\lambda_i}}{x_j!} \right)^2, \quad i = 0.01, 0.02, \ldots, 10 \tag{2}$$

In Equation 2, λ_i is the Poisson parameter estimate with value i, x_j denotes j number of passenger arrivals, f_j is the observed frequency of j number of passenger arrivals, and n is the total number of time intervals. The second term within the sum in Equation 2 represents the Poisson expected frequency of j number of passenger arrivals ($\lambda_i = i$). The average number of passenger arrivals per minute at a station that corresponds to the minimum SSE is the Poisson parameter estimate that is used in this study.

Headway and the Passenger Desired Waiting Time

The traditional model expresses expected passenger waiting time as half of the bus headway. Salek and Machemehl (1999) presented the half headway model as follows:

$$\bar{w} = \frac{\bar{t}}{2} \tag{3}$$

where $\bar{w}$ is the average waiting time of a passenger arriving at the bus-stop and $\bar{t}$ is the bus headway. In this study, the transport vehicle headway must be determined to compute the load factor and passenger waiting time. However, CBS and HPBS are not currently operational in Davao City; hence, no headway data can be gathered. Thus, we propose to formulate the transport vehicle headway.

We begin with an assumption that the service time is based on the desired waiting time of the passengers. We used Equation 3 to compute the headway for the transport vehicle, where $\bar{w}$ represents the passenger desired waiting time (PDWT) while $\bar{t}$ represents the vehicle headway (H). In other words, we can rewrite Equation 3 as follows:

$$\text{H} = 2 \times \text{PDWT} \tag{4}$$

In this study, we estimate the value of passenger desired waiting time using the data collected from the survey. A total of eighty respondents took the survey resulting from ten random passengers chosen from eight stations. We compute the passenger desired waiting time using the following formula:

$$\text{PDWT} = \frac{\sum_{i=1}^{80} y_i}{80} \tag{5}$$

where y_i is the desired waiting time of respondent i. Both the headway and passenger desired waiting time are measured in minutes.

Load Factor

The load factor (LF) is the ratio of demand to supply and is computed by taking the quotient of the two quantities. It can be computed using the data collected by boarding and alighting of passenger during the operation period along the bus route (Strathman and Hopper 1993; Chen et al. 2009).

In this study, the expected load factor multiplied to the vehicle seating capacity is the average load or number of passengers carried by the vehicle from Mintal Public Market to Ulas Crossing during the observation period.

We compute the load factor using the passenger demand (PD) and transport supply (TS) determined from the work of Mendoza and San Diego (2008).

From Mendoza and San Diego (2008), the transport supply is the product of the transport vehicle frequency F and the passenger seating capacity C. Thus, if $C(l)$ represents the passenger seating capacity of the transport option l (l = CBS; HPBS), we write the transport supply of vehicle l in station i as follows:

$$TS(l)_i = F \times C(l)\ , \quad l = 1, 2, \ldots, 8 \tag{6}$$

The service frequency F for our transport options is the number of times the vehicle passes in the station during the observation period and is given by the following:

$$F = \frac{120}{H} \tag{7}$$

i.e., two hours or 120 min divided by the headway.

We also assume in this study that the transport vehicle is empty as it arrives in Mintal Public Market station since loading and unloading behavior of the existing transport vehicle is unknown before it arrives at the said station. Now according to Davao Sustainable Executive Board (2013), CBS has a maximum seating capacity of 60 seats while HPBS has a maximum seating capacity of 90 seats. Using Equation 6 and prior knowledge of maximum seating capacity, the transport supply of CBS and HPBS in station i are shown below, respectively:

$$TS(CBS)_i = 60F \quad \text{and} \quad TS(HPBS)_i = 90F \tag{8}$$

In this study, we define P_{arrive} as the number of passenger arrivals in each station in a minute. Let X_i be the average number of passenger arrivals per minute in station i. Since there are 120 one-minute intervals during the observation period per station, then X_i for both transport options is computed as follows:

$$\bar{X}_i = \frac{\sum_{j=1}^{120} P_{arrive(j)}}{120} \tag{9}$$

where $P_{arrive(j)}$ is the number of passenger in the jth one-minute interval that arrived at the ith station.

The number of passenger arrivals per station (PA_i) during the morning rush hour for both transport options is given by the following:

$$PA_i = (\bar{X}_i \text{ arrivals / min}) \times 120 \text{ min} \tag{10}$$

The passenger demand per transport option in each station ($PD(l)i$) is the expected number of passengers that the public transport vehicle carries from one station during the observation period. Let us denote P_{unload} as the number of passengers that the transport vehicle unloads as it arrives in the station in a minute. The number of unloaded passengers implies the number of available seating capacity. Since we assume that the transport vehicle that arrives at the Mintal Public Market is empty, P_{unload} in this station is set to zero. Therefore, the passenger demand for transport option l in the ith station ($PD(l)_i$) is computed as follows:

$$PD(l)_i = PD(l)_{i-1} + PA_i - \sum_{i=1}^{8} P_{unload(i)}\ , \tag{11}$$

$$PD(l)_0 \equiv 0\ , \quad \text{and} \quad P_{unload(1)} \equiv 0 \tag{12}$$

Therefore, we formulate the expected load factor for transport vehicle l at station i as follows:

$$LF(l)_i = \frac{PD(l)_i}{TS(l)_i} \tag{13}$$

where $TS(l)i$ and $PD(l)i$ are given by Equations 6 and 11, respectively.

Passenger Waiting Time

We approximate the passenger waiting time at the station using the $M / M^k / 1$ model and carry out the approximation by first defining the cycle time (CT). Wu et al. (2011) defined cycle time as the total passenger expected waiting time in the system. Here we define cycle time as the time that elapsed from the arrival of a vehicle until the next arrival. We decompose cycle time into three parts: (1) the wait-to-batch time (WTBT), the time spent to accumulate the fixed batch size k passengers; (2) the queueing time (QT), the passenger waiting time after the fixed batch size k passengers has been accumulated; and (3) the service time (ST). In this study, service time corresponds to the transport vehicle headway.

For emphasis, we redefine queueing time as "passenger waiting time" in this study. We apply the structure and formulas of the single server batch queueing model discussed by Wu et al. (2011) and obtain the cycle time for transport option l in ith station as follows:

$$\mathrm{CT}(l)_i = \mathrm{PWT}(l)_i + \mathrm{WTBT}(l)_i + \mathrm{ST} \quad (14)$$

To compute for passenger waiting time, we need the following quantities: (1) $60 \times \lambda$, the arrival rate of passengers by foot (passengers/hr); (2) μ, the service rate of the bus (bus arrival/hr); and (3) k, the fixed batch size. The service rate is the frequency of the transport vehicle per hour. Since there are 60 min in an hour, the service rate for both transport options is given as follows:

$$\mu = \frac{60}{\mathrm{ST}} \quad (15)$$

where service time is measured in terms of minutes.

The fixed batch size for transport option l in station i, $k(l)_i$, is determined by the average number of passengers that arrive at the station and waiting for a ride within the service time such that WTBT ≤ ST. By little algebraic manipulation, we obtain the following inequality:

$$k(l)_i \leq (2\,\lambda_i \times \mathrm{ST}) + 1 \quad (16)$$

Equation 16 is derived from wait-to-batch time formula given by the following:

$$\mathrm{WTBT}(l)_i = \frac{k(l)_i - 1}{2\text{ hr} \times 60\text{ min/hr} \times \lambda_i \text{passengers/min}} \quad (17)$$

Using the cycle time formula of Wu et al. (2011), we derive the cycle time for transport option l at station i as follows:

$$\mathrm{CT}(l)_i = \frac{1}{\lambda_i k(l)_i}\left(\frac{k(l)_i(k(l)_i - 1)}{2} - \frac{x^2(1 - x^{k(l)_i - 1})}{(1 - x)^2} + \frac{(k(l)_i - 1)x^{k(l)_i + 1}}{1 - x} + \frac{60\lambda_i k(l)_i}{\mu} + \frac{60\lambda_i x}{\mu(1 - \mathrm{x})}\right) \quad (18)$$

with

$$x(l)_i \approx 1 - \frac{2(1 - \rho(l)_i)}{k(l)_i + 1} - \frac{4(k(l)_i - 1)}{3(k(l)_i + 1)^2}(1 - \rho(l)_i)^2$$

$$\text{and} \quad \rho(l)_i = \frac{60\lambda_i}{k(l)_i} \quad (19)$$

In Equation 19, $\rho(l)_i$ represents the utilization of transport option l at station i.

Hence, from Equation 14, the passenger waiting time for transport option l at station i is given by the following:

$$\mathrm{PWT}(l)_i = \mathrm{CT}(l)_i - \mathrm{WTBT}(l)_i - \mathrm{ST} \quad (20)$$

where $\mathrm{CT}(l)_i$ is given by Equation 18 with Equation 19, $\mathrm{WTBT}(l)_i$ is given by Equation 17, and the service time is given by the headway formula in Equation 4. The temporal quantities in Equation 20 are measured in minutes.

Results and Discussion

Poisson Distribution Fitting of Passenger Arrivals for Each Station

As a starting point, we first verify that the passenger arrivals per station follow a Poisson distribution using Chi-square goodness-of-fit test (Table 1). The results for the Poisson distribution fitting of the passenger arrivals per unit time (per minute and per hour) in each station show that the estimated arrival rate of the passengers is lowest at UC and highest at PB with average arrivals of one and six passengers per minute (equivalently, 73 and 379 passengers per hour), respectively (Table 1).

Transport Vehicle Headway, Service Time, and Service Rate

Based on survey data, the passenger desired waiting time at the station has the mean of 1.5 min. Moreover, we found that the headway is approximately 3 min using Equation 4. This implies that the service time is also roughly 3 min. It follows from Equation 7 that the transport vehicle frequency during the observation period of this study is 40. The service rate of both transport options is 20 vehicles per hour. These

TABLE 1 Chi-square goodness-of-fit test results for Poisson distribution of passenger arrivals in each station

Station	P-value*	Passenger / min	Passenger / h
Mintal Public Market (MPM)	0.064	4.16	249
Panadero Bakery (PB)	0.055	6.32	379
Holy Spirit Hospital (HSH)	0.330	2.27	136
Relocation Site (RS)	0.082	4.65	279
Grean Meadows Subdivision (GMS)	0.199	2.50	150
Catalunan Crossing (CC)	0.526	5.23	313
Pag-Ibig (P)	0.520	2.24	134
Ulas Crossing (UC)	0.182	1.22	73

NOTE *At 5% level of significance.

TABLE 2 Expected load factor and passenger waiting time of conventional and highly prioritized bus services in the eight loading and unloading stations from Mintal Public Market to Ulas Crossing, Davao City

Station	Conventional bus service		Highly prioritized bus service	
	Load factor (%)	Passenger waiting time (min)	Load factor (%)	Passenger waiting time (min)
Mintal Public Market (MPM)	20.79	1.02	13.86	1.02
Panadero Bakery (PB)	47.83	1.00	31.89	1.00
Holy Spirit Hospital (HSH)	53.96	1.01	35.97	1.01
Relocation Site (RS)	76.17	1.01	50.78	1.01
Grean Meadows Subdivision (GMS)	86.33	0.90	57.56	0.90
Catalunan Crossing (CC)	100.00	2.69	71.83	0.95
Pag-Ibig (P)	100.00	4.20	78.19	0.97
Ulas Crossing (UC)	88.00	0.95	70.19	0.95

quantities allowed us to compute for the expected load factor and passenger waiting time of CBS and HPBS in each station (Table 2).

Expected Load Factor of CBS and HPBS

The expected load factor of a vehicle is computed by dividing the passenger demand with the transport supply. The transport supply of the vehicle is easily computed using Equation 6. The maximum passenger seating capacity for CBS is 60 and for HPBS, 90 (DSEB 2013). Substituting the calculated vehicle frequency of 40 to Equation 8, the computed transport supply of CBS and HPBS are 2400 and 3600, respectively.

Computing the passenger demand for CBS and HPBS using Equation 11, we observe that the passenger demand shows an increasing trend between MPM and CC stations but drops between P and UC stations for both transport options (Figure 2A). This trend is because passenger arrival rate is lesser than the rate of unloaded passengers in the latter station. Moreover, we observe here that the passenger demands of the transport options are equal from MPM up to GMS stations but differ in latter stations, with HPBS showing higher passenger demand. The observed difference in the passenger demand of CBS and HPBS in some stations is due to the differences of their transport supply.

The passenger demand for CBS at CC and P stations is equal to its transport supply (2400) though, in actuality, the passenger arrival is greater than 2400. The passenger demand of CBS is fixed to 2400 since we assumed that the vehicle does not carry passengers more than its maximum seating capacity. We consider

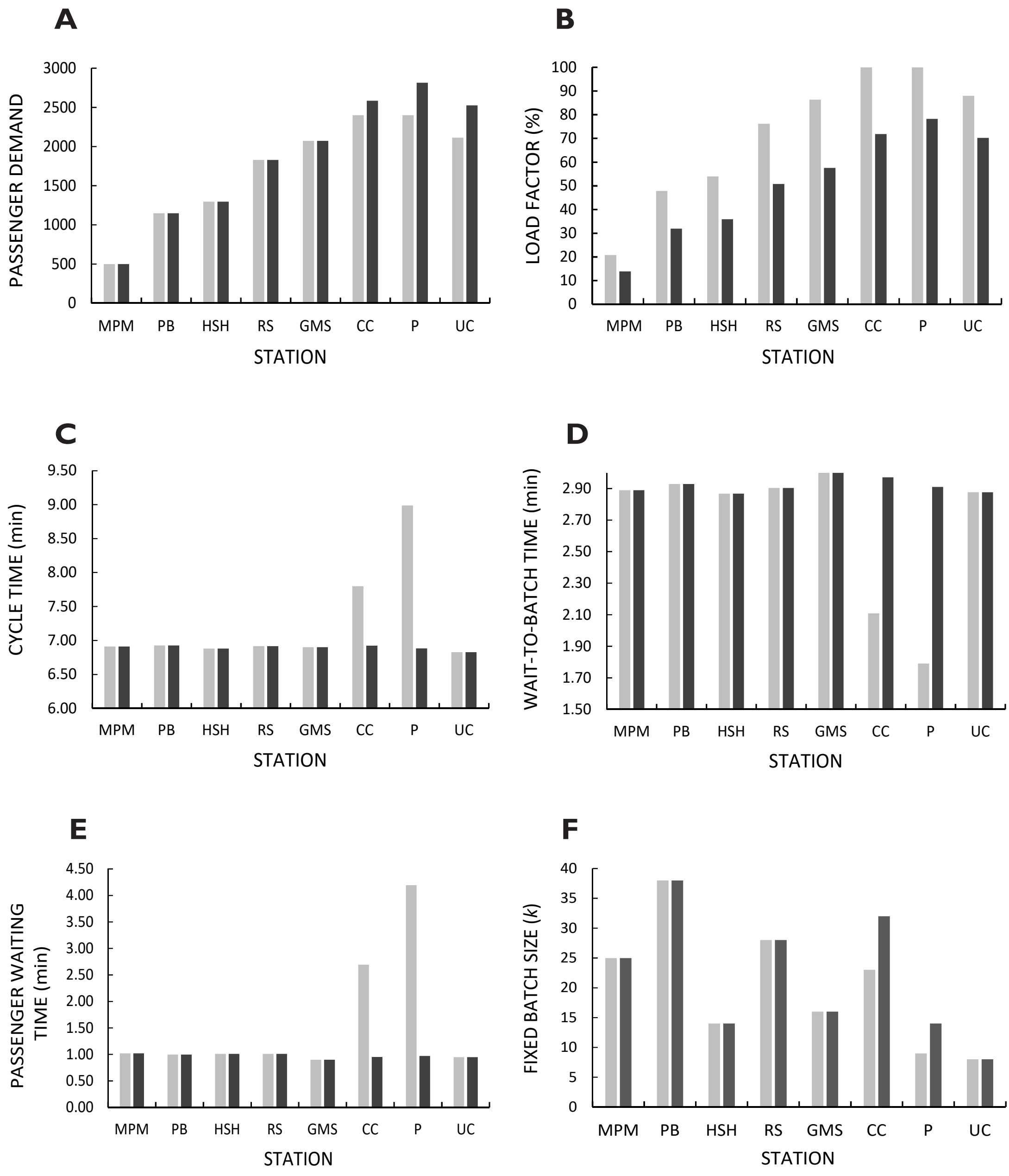

FIGURE 2 The passenger demand (A), load factor (B), cycle time (C), wait-to-batch time (D), passenger waiting time (E), and fixed batch time (F) of conventional bus service (■ CBS) and highly prioritized bus service (■ HPBS) in eight loading and unloading stations in the Mintal area, Davao City

Stations: MPM - Mintal Public Market, PB - Panadero Bakery, HSM - Holy Spirit Hospital, RS - Reclamation Site, GMS - Green Meadows Subdivision, CC - Catalunan Crossing, P - Pag-Ibig, UC - Ulas Crossing the excess passengers as left-behinds and can ride the next transport vehicle, if it is not fully loaded. Consequently, the HPBS is able to meet the passenger demand from MPM to UC stations while the CBS fails to supply the transport demand in CC and P stations.

Using Equation 13 and prior information to compute for the load factor of the CBS and HPBS, we observe that CBS has higher load factor than HPBS (Figure 2B) because both transport options have almost the same transport demands and only differ significantly in their transport supplies, i.e., TS(CBS) ≤ TS(HPBS). Furthermore, at CC and P stations, we find that CBS has a load factor of 100%. The load factor of both transport options increases from station MPM to station P then decreases as the vehicle travels toward the UC station (Figure 2A). This trend is again attributed to higher unloading rate of the vehicle between stations P and UC.

Passenger Waiting Times of CBS and HPBS

We are left to determine the cycle time and wait-to-batch time to compute the passenger waiting time for each transport option. Using Equation 18, we compute the cycle time of CBS and HPBS for each station, and results show that cycle time of CBS ranges from 6.83 to 8.99 min while HPBS ranges from 6.83 to 6.93 min (Figure 2C). Both transportation options show equal cycle times in all stations except at CC and P stations. This finding is explained by the high passenger demand that CBS fails to satisfy, causing more left-behind passengers and increasing its cycle time.

Computing for the wait-to-batch time for CBS using Equation 17, we see that the wait-to-batch time for CBS ranges from 1.79 to 3.00 min while for HPBS it ranges from 2.88 to 3.00 min. Similar to cycle times, both transport options show equal wait-to-batch times in all stations except at the CC and P stations. Cycle time is generally higher at stations CC and P than wait-to-batch time (Figures 2C and D).

We finally compute the passenger waiting time using Equation 20 (Figure 2E). The passenger waiting time of CBS is between 0.9 and 4.2 min while that of HPBS has a shorter span, which is between 0.9 and 1.02 min. Since passenger waiting time is linearly related to cycle time and wait-to-batch time, we expect passenger waiting time across stations to have a similar pattern as cycle time and wait-to-batch time (compare Figures 2C, E, and E).

The failure of CBS in satisfying the actual passenger demand has a dramatic effect to its cycle time, wait-to-batch time, and passenger waiting time at CC and P stations. We assert that the observed behavior is due to variation in the fixed batch size (k) across stations.

In computing fixed batch size, CBS shows lower fixed batch size than HPBS at stations CC and P (Figure 2F). We also observe that the fixed batch size is lowest at UC stations for both transport options. This pattern is also observed in the plot of cycle time (Figure 2C) and passenger waiting time (Figure 2E). Focusing on stations CC and P (Figures 2C to F), we may conclude that fixed batch size is directly proportional to wait-to-batch time and inversely proportional to cycle time and passenger waiting time. Thus, a low fixed batch size implies a low wait-to-batch time and high cycle and passenger waiting times.

Summary and Conclusion

In this study, we assessed the viability of two proposed transport options for Davao City. Our assessment is based on the comparison between conventional bus service and highly-prioritized bus service in terms of their expected load factor and passenger waiting time. Using a standard technique, we have computed for the expected load factor of each transport option. On the other hand, we have developed a novel approach to compute the passenger waiting time of the transport option. The said approach is derived from a single server batch service queuing model by Wu et al. (2011).

The performance of CBS and HPBS is projected from the existing public transport vehicle demand and supply in the city. In our analysis, we have considered the passenger demand and transport supply in the Mintal area (Mintal Public Market to Ulas Crossing) during the morning rush hour (6:30 to 8:30 AM). We gathered data over the 120-minute time interval, such as actual passenger arrivals per minute and actual number of unloaded passengers per minute in each loading and unloading station. We have surveyed the passenger desired waiting time from ten random waiting passengers for every station.

We have shown that passenger arrivals per station follow a Poisson distribution, which implies that inter-arrival times of passengers is exponentially distributed. Since the CBS and HPBS are not yet operational, we do not have actual data for the service times. However, the number of transport arrivals is commonly modeled by a Poisson distribution (Rengaraju and Rao 1995; Mathew 2014); thus, we assumed that the time between two arrivals or service time follows an exponential distribution (Weisstein 2017). Taking the assumption that the service times of transport vehicles follow an exponential distribution, we have approximated the passenger waiting time performance of the transport options using a single server batch service queueing model. According to the results of our survey, we have determined the headway or service time of the transport vehicle, which is 3 min. Hence, the frequency of both transport options during the observation period is 40.

We have observed that CBS has higher load factor than HPBS. Conventional bus service has the lowest load factor at Mintal Public Market with 20.79% and highest at Catalunan Crossing and Pag-Ibig with 100%. On the other hand, HPBS has the lowest load factor at Mintal Public Market with 13.86% and highest at Pag-Ibig with 78.19%. Though CBS has higher load factor, it fails to satisfy all the passenger demands at Catalunan Crossing and Pag-Ibig stations. These numbers point to HPBS as a better option in meeting the public transport need in Mintal area during the morning rush hour.

Another finding of our study is that CBS and HPBS has varying passenger waiting times at Catalunan Crossing and Pag-Ibig stations. For conventional bus service, the passenger waiting time is lowest for Green Meadows at 0.9 min and highest for Pag-Ibig with 4.2 min. For HPBS, the passenger waiting time is also lowest for Green Meadows at 0.9 min but highest for Mintal Public Market with 1.02 min. We also found that the inability of CBS to satisfy the passenger demand results in an increase in passenger waiting time. Thus, HPBS has a better performance in controlling the passenger waiting time.

Based on our overall analysis of the projected performance of the proposed transport options, we suggest that policy makers should consider HPBS as a better public transport option for Davao City in terms of load factor and passenger waiting during morning rush hour. Our general conclusion is limited by the stations and time-frame of data gathering we considered in this study. Nevertheless, we recommend future researchers to apply our developed methodology to perform an analysis of the projected load factor and passenger waiting time of public transport options for other times, e.g., off-peak hours and evening rush hours. One extension of this work is to adopt the method of Kornfeld et al. (2014) to identify the optimal number of buses to run during different time periods with minimal passenger waiting times computed according to the formulation of Lees-Miller (2014). This study and future analysis could provide new insights about the viability of the proposed public transport vehicles.

Acknowledgment

This paper reports on the undergraduate special problem of the main author for a BS in Applied Mathematics at the University of the Philippines Mindanao.

References

Abdi H. 2007. The method of least squares. Encyclopedia of measurement and statistics. CA: Thousand Oaks.

[ADB] Asian Development Bank. 2013. 1 million USD ADB project launched to support Davao's sustainable transport. [Cited 17 Jan 2014] Available at: https://www.adb.org/news/1-million-adb-project-launched-support-davaos-sustainable-transport.

Ayyappan G, Devipriy G, Subramanian AMG. 2013. Study of impact of negative arrivals in single server fixed batch service queueing system with multiple vacations. Appl Math Sci 7(140): 6967–6976.

Bluman AG. 2009. Elementary statistics: A step by step approach. New York (NY): McGraw-Hill Higher Education.

Board DCE. 2013. Philippine Institute of Civil Engineers Inc. 39th National Convention. [cited 17 Jan 2014] Available at: http://www.picenatcondavao.com.

Carillo LA. 2013. Prioritized bus service better option for Davao City. [Cited 17 Jan 2014] Available at: http://balita.ph/2013/10/10/prioritized-bus-service-better-option-for-davao-city/.

Chen X, Yu L, Zhang Y, Guo J. 2009. Analyzing urban bus service reliability at the stop, route and networks levels. J Trans Res 43A: 722–734.

[DSEB] Davao Sustainable Executive Board. 2013. Project data sheet. [Cited 17 Jan 2014] Available at: https://www.adb.org/projects/45296-003/main.

Deligero GG. 2013. The state of Davao's public transport. EDGE Davao, 6, p4.

Fan W, Machemehl RB. 2002. Characterizing bus transit passenger waiting times, pp. 5–8. In: 2nd Material Specialty Conference of the Canadian Society for Civil Engineering, Montreal, Quebec, Canada.

Fan W, Machemehl RB. 2009. Do transit users just wait for buses or wait with strategies? Some numerical results that transit planners should see. Trans Res Rec 2111: 169–176

Gong H, Chen X, Yu L, Wu L. 2013. An application-oriented model of passenger waiting time based on bus departure time intervals. Transportation Research Board, Washington, DC.

Hillier F, Lieberman G. 2001. Introduction to operations research. New York: McGraw-Hill.

Kornfeld S, Ma W, Resnikoff A. 2014. Optimizing bus schedules to minimize waiting time. Operations Research II: 21–392.

Lees-Miller JD. 2014. Minimizing average passenger waiting time in personal rapid transit systems. [Southampton (UK)]: Transportation Research Group, University of Southampton.

Lowry R. 2013. VassarStats: Website for statistical computation. New York (NY): Vassar College.

Lumawag RJF. 2013. Davao City council to present report on sustainable transport. Sun Star. [cited 17 Jan 2014] Available at: https://www.pressreader.com/philippines/sunstar-davao/20131217/281633893053481.

Mendoza MV, San Diego MG. 2008. Determination of route measured capacity of buses for EDSA. [Quezon City (Philippines)]: University of the Philippines Diliman.

Reyes A. 2012. Problem of transportation system in the Philippines. [cited 23 Jan 2014] Available at: https://www.scribd.com/doc/114400304/Problem-of-Transportation-System-in-the-Philippines.

Salek MD, Machemehl RB. 1999. Characterizing bus transit passenger wait times. [Austin (TX)]: University of Texas at Austin. No. SWUTC/99/167211-1.

Strathman J, Hopper J. 1993. Empirical analysis of bus transit on-time performance. J Trans Res 17A: 107–113.

Taha HA. 2003. Operations research: an introduction. 7th ed. New Delhi (India): Prentice-Hall of India.

Weisstein EW. Exponential distribution. From MathWorld: A Wolfram Web Resource [cited 5 Sept 2017) http://mathworld.wolfram.com/ExponentialDistribution.html

Wu K, McGinnis LF, Zwart B. 2011. Approximating the performance of a batch service queue using the ${\ rm M/M}^{\ rm k}/1$ model. IEEE Trans Autom Sci Eng 8(1): 95–102.

Zhao F, Chow L-F, Li M-T, Liu X. 2005. A transit ridership model based on geographically weighted regression and service quality variables. FL: Department of transportation. 32399-0480.