A STUDY ON THE PERFORMANCE OF UNIVERSITY MALAYA CAMPUS BUS SERVICE USING DWELL TIME MODEL AND PASSENGER DISTRIBUTION ANALYSIS

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FACULTY OF ENGINEERING
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A STUDY ON THE PERFORMANCE OF UNIVERSITY MALAYA CAMPUS BUS SERVICE USING DWELL TIME MODEL AND PASSENGER DISTRIBUTION ANALYSIS

ABSTRACT

Accessibility and mobility are key to a sustainable transport system for the community within a green university campus. To encourage more sustainable transport usage, public transport such as campus bus service are provided for students to commute between academic buildings and residential areas on campus. The current operating timetable of the campus bus service is made by the Student Affairs Division based on the observation of bus service in the past few years. This research aimed to study the capability of the campus bus service in University of Malaya (UM) to accommodate the demand of students. A survey questionnaire was distributed among students to identify their transportation mode, willingness and satisfaction level on current campus bus service. To identify the congruity and appropriateness of the current bus timetable, a passenger count survey was done to identify the distribution of passenger demand. The passenger count data was analysed with respective bus capacity to obtain the passenger load factor (PLF). PLF was used to identify the capability of the current bus service to cater to passenger demand. Besides, the bus trip time data was analysed with passenger count data to study and evaluate the effectiveness of the campus bus service. Other than the number of passengers boarding and alighting, the station type, bus type used, and PLF also affected bus dwell time. A statistical software, Minitab was used to construct dwell time models through multiple linear regression analysis and examine the effect of PLF on dwell time. Bus timetable optimisation was used to generate a demand-based bus timetable for the UM campus bus routes. The proposed bus timetable has shorter dwell time and passenger waiting time than the current bus timetable. By implementing the proposed optimal bus

timetable, the transit capacity, speed, and reliability of UM's campus bus service can be enhanced.

Keywords: bus performance analysis; passenger demand distribution; person capacity; dwell time; passenger load factor.

KAJIAN MENGENAI PRESTASI PERKHIDMATAN BAS KAMPUS UNIVERSITI MALAYA MENGGUNAKAN MODEL MASA BERHENTI DAN ANALISIS TABURAN PENUMPANG

ABSTRAK

Kebolehcapaian dan mobiliti merupakan kunci-kunci kepada sistem pengangkutan yang mampan bagi komuniti dalam kampus universiti hijau. Untuk menggalakkan penggunaan pengangkutan yang lebih mampan, pengangkutan awam seperti perkhidmatan bas kampus disediakan kepada pelajar untuk berulang-alik antara bangunan akademik dan kawasan kediaman di dalam kampus. Jadual operasi semasa perkhidmatan bus kampus dibuat oleh Bahagian Hal Ehwal Pelajar berdasarkan pemerhatian perkhidmatan bas beberapa tahun lalu. Kajian ini bertujuan untuk mengkaji keupayaan perkhidmatan bas kampus di Universiti Malaya (UM) untuk menampung permintaan pelajar. Soal selidik tinjauan diedarkan kepada pelajar untuk mengenal pasti mod pengangkutan perjalanan, kerelaan dan tahap kepuasan perkhidmatan bas kampus. Untuk mengenal pasti kesesuaian jadual waktu bas semasa, kajian kiraan penumpang dilakukan untuk mengenal pasti taburan permintaan penumpang. Data kiraan penumpang dianalisis dengan kapasiti setiap bas untuk mendapatkan faktor muatan penumpang (PLF). PLF digunakan untuk mengenal pasti keupayaan perkhidmatan bas semasa untuk memenuhi permintaan penumpang. Selain itu, data masa perjalanan bas dianalisis dengan data kiraan penumpang untuk mengkaji dan menilai keberkesanan perkhidmatan bas kampus. Selain dari jumlah penumpang yang naik dan turun, jenis stesen, jenis bas yang digunakan, dan PLF juga mempengaruhi masa berhenti bas. Perisian statistic Minitab digunakan untuk membina model masa berhenti melalui analisis regresi berganda linear dan mengaji kesan PLF terhadap masa berhenti. Pengoptimuman jadual bas digunakan untuk menghasilkan jadual bas yang berdasarkan permintaan untuk laluan bas kampus UM. Jadual bas yang dicadangkan mempunyai masa berhenti dan masa menunggu penumpang yang lebih

pendek daripada jadual bas semasa. Dengan melaksanakan jadual waktu bas yang sesuai, kapasiti, kelajuan, dan kebolehpercayaan transit perkhidmatan bas kampus UM dapat dipertingkatkan.

Kata-kata kunci: analisis prestasi bas; taburan permintaan penumpang; kapasiti orang; masa berhenti bas; faktor muatan peumpang.

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LIST OF SYMBOLS AND ABBREVIATIONS

CBD	:	Central Business District
GA	:	Genetic Algorithm
GPS	:	Global Positioning System
OLS	:	Ordinary Least Square
PHF	:	Peak Hour Factor
PLF	:	Passenger Load Factor
UM	:	University of Malaya

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CHAPTER 1: INTRODUCTION

Universities occupy large areas of land and the growth in their populations has likely increased traffic within the universities. The trends of motorisation in universities are matching those in society and are causing traffic congestion in the campus. In some ways, traffic in universities is worsened due to the admission of greater numbers of matured students, which probably raises the proportion of car-owning students. University of Malaya (UM) is the only signatory of the *Talloires* Declaration in Malaysia where the university community has embarked on a voluntary commitment to improve energy efficiency, conserve resources and enhance environmental quality by incorporating sustainability into their systems. As a result of it, the University of Malaya (UM) community needs to embark on more sustainable campus planning as dedicated in the *Talloires* Declaration. Innovative sustainable transportation policies need to be introduced to reduce the dependency on private vehicles. At the same time, a public transportation system, which is the campus bus service, has been implemented and promoted on UM campus.

1.1 Background

The campus bus service plays a key role as a public transportation on university campus. It provides easy accessibility and promotes connectivity by providing the campus community with riding services to commute between the living residential hostels and academic areas on campus. Aiming to cater to the demands of the community, the planning of the campus bus service must be accessible, provide connectivity and meet the mobility needs of the passengers, which requires a demand-based, high efficiency and sustainable operating bus timetable and a suitable type of bus for operation.

A campus bus service is widely provided by most of the universities in Malaysia to their community. On most of the university campuses, the transit bus takes up the largest portion of the transportation modal which the students heavily rely on. Normally, they commute with the campus bus to travel from residential hostels to faculties or administrative buildings. A study shows that the campus bus service is greatly demanded by most of the university students, especially those living on campus (Hashim et al., 2013).

Based on the perception of both the passengers and bus operators, transit reliability is one of the major factors that make a successful transit system (*TCQSM*, 2013). To promote the campus bus service, the bus operator needs to provide a reliable transit system that fulfils some service criteria such as demand-based, short passenger waiting time at bus station and easy access to the bus for passengers. As a result, a reliable transit system can reduce the operational costs for operators and the dependency on private cars in the campus.

In UM, the campus bus service travels between residential colleges, academic zones, administrative buildings and UM Central, which is an integrated bus station that serves as the interchange terminal for other transportation modes and services, such as RapidKL buses, MRT feeder buses and taxis. The campus bus service is equipped with an operation timetable published by the Student Affairs Division of UM. Provision is also made for off campus resident students who wish to transit between their resident areas and the UM campus.

To understand the bus service performance, a detailed analysis has to be done to evaluate the passenger demand, the service quality provided by the bus operator, and the potential development of the growing passenger demand and service reliability. With the establishment of a campus transportation plan, University of Massachusetts Lowell has extensively studied the existing transportation performance as well as the potential of a modal shift from private to public transit, aiming to reduce the number of private vehicles and to resolve the issues of limited parking spaces (*Campus Transportation Plan UMass Lowell*, 2011). The report of campus transportation system evaluation developed by University of Wisconsin has reviewed the overall transit network on its campus to examine how well the existing routes are matched to the need ("Campus Transportation System Evaluation," 2013).

The results obtained from the passenger demand and person capacity analysis can be used to optimise and determine the changes that can be made to the current operational schedule to improve the existing condition of the riding services (Carreon & Florendo, 2013). Moreover, the perspective of the bus passengers on service quality can be explored through a questionnaire survey method. The results analysed from the questionnaire survey can be used as recommendations for the improvement of the bus service.

Many quality aspects of the public transport service should be improved in order to increase its share in the transportation system. A campus bus service with high service quality is believed to result in a transportation modal shift from private car use to the campus bus. The need to run a campus bus service on a limited budget while providing a sufficient number of buses at different time periods to cater to passenger demand with high service quality is putting a lot of pressure on the university authority. Therefore, ensuring a free campus bus service with high quality is in the interest of all university authorities when it comes to campus transportation.

In this research, a study was performed on the transportation modal shift from private car usage to campus bus service on UM campus. This study focused on promoting the use of campus bus service by upgrading the current campus bus timetable to solve the traffic-related issue on campus. A transportation mode shift from private car to campus bus service can be done by understanding the current passenger demand distribution and by enhancing the bus services reliability and facilities as well as by implementing supportive policies.

1.2 Problem Statement

The UM Campus, which is located in Kuala Lumpur, has several modes of public transportation, such as the campus bus service, RapidKL bus, MRT feeder bus and taxi. There are five campus bus routes (Bus Routes A, B, C, D, and E) provided by the UM authority to serve UM citizens. Route A and Route B are on-campus bus routes whereas Routes C, D and E are off-campus bus routes. Bus Route A and B are the focus bus routes in this study, are highly occupied during certain periods and provide frequent and fast trips within the UM campus. The departure strategy of on-campus bus routes is to have three buses depart from the origin in an hour for off-peak hours and six buses depart form the origin in an hour during peak hours.

Considering that the number of students in UM campus vary every academic year, depending on the number of students enrolled and graduated each year, there is a need for constant revision and enhancement of the campus bus system for it to be a successful one. The current bus timetable of the UM campus bus service is designed with even departure times where the bus service is not efficient when the passenger demand varies. The efficiency of a transit bus service is challenging due to the fluctuation of passenger demand throughout. Moreover, the passenger demand is high during peak hours, whereby buses are overcrowded and standing passengers near the front door are blocking the vehicle side view, which creates a blind spot for the bus driver. Furthermore, resources wastage occur frequently during off-peak hours due to the oversupply of person capacity.

Due to the high dependency of UM students on the campus bus service and the insufficient number of bus trips during high passenger demand periods, people spend more time and money on travel. Therefore, the current bus service performance and shortcoming need to be identified in order to improve the efficiency of the campus bus service and develop a sustainable bus transit system.

1.3 Research Gap

There are two research gaps in this study. The onboard crowdedness of bus is less focused on previous research. Most of the previous research use dummy variable to represent the passenger overloaded situation in bus. In this study, the passenger load factor is used to represent the onboard crowdedness of bus and examine the relationship with bus dwell time using multiple linear regression analysis.

Current researches also paid less attention on the effects of dwell time on the efficiency of a bus timetable. Most of the studies on bus timetable optimisation are focus on optimise the vehicle travel time. This research is focus on generate a demand-based bus timetable by minimising bus dwell time and passenger waiting time.

1.4 Research Questions

To provide a clear direction of the research and to establish the best methodology approach, six research questions are constructed as mentioned below:

i. What is the opinion and recommendation on current bus service from UM student?
ii. What are the peak hours with high passenger demand on UM campus bus service?
iii. What is the passenger demand distribution especially during peak hours?
iv. What are the factors that affecting bus dwell time?
v. Is there any relationship between passenger load factor and bus dwell time?
vi. What are the factors need to considered in order to improve UM campus bus timetable?

1.5 Research Aim and Objectives

This research aims to evaluate the performance of the UM campus bus service by focusing on the relationship between the passenger demand and the person capacity of the bus service. Questionnaire survey was distributed to UM students to collect their satisfactory level on campus bus service. Passenger load factor was used to analyse the person capacity of the campus bus service.

In order to develop and recommend an efficient sustainable campus bus system in UM campus, here are the objectives of this study as below:

i. To identify the passenger satisfactory level on the performance of the campus bus service.
ii. To evaluate the effectiveness of the bus service by using passenger load factor and peak hour factor.
iii. To examine the factors of bus dwell time with multiple linear regression model and the effect of passenger load factor (PLF) level on dwell time.
iv. To generate a demand-based bus timetable that is based on timetable optimisation by minimising dwell time and passenger waiting time.

1.6 Research Scopes

A questionnaire is distributed by using Google Forms platform to identify the satisfactory level of passengers and measure the performance of the current campus bus service. Passenger demand and person capacity analysis are performed only on on-campus bus routes to evaluate the effectiveness of the campus bus service. Next, factors of bus dwell time are identified with multiple linear regression analysis by using statistical software - Minitab. The assessment of the congruity and appropriateness of the campus bus service is studied and bus timetable optimisation is used to propose an optimal bus timetable that is able to cater to the current passenger demand by minimising total dwell time and total passenger waiting time.

1.7 Dissertation Outline

This dissertation is made up of five main chapters and organised in the following way. The first chapter gives a brief overview on the transit bus service, problem statement of this study, its objectives, scopes and the outline of the dissertation. The second chapter is the literature review, which provides an overview on previous studies on transit bus performance analysis. This chapter also focuses on research gaps in this field. Chapter three describes the design, synthesis, characterisation and evaluation of passenger count and trip time data. Besides, the method used in analysing the data are also discussed. Chapter four shows the results of the analyses on the questionnaires, passenger demand and person capacity. The dwell time model and the optimal bus timetable are also presented and discussed in this chapter. Finally, the last chapter assesses the conclusion of this study with a general discussion of the results and makes some recommendations as well as provides topics for possible future studies.

CHAPTER 2: LITERATURE REVIEW

2.1 Transportation Planning

Systematic planning is a necessity for demand-based development (*Traffic Data Collection and Analysis*, 2004). It relates accessibility and mobility of its end users with the determination of required capacity and infrastructure, or enhanced technology and management system. Transportation planning is often integrated into infrastructure development and economic planning, which will also take into account the environmental aspects of the grand vision to provide ease of accessibility to the community.

While these plans comply with the transport demand, the planning of a transportation system is often associated with the aim to influence passenger travel behaviour and to encourage a modal shift from private to public transportation. A few objectives are often integrated within the transportation planning so that a more cost-effective and environmentally sustainable solution can be obtained.

The transportation planning process is always a complex integration of different models and analytical tools to generate a complex collaboration of transportation system performance (Institute of Transportation Engineers, 2006). A logical process has to be obeyed in transportation planning as per the following steps:

i. Developing a community or study area vision
ii. Acquire more specific information
iii. Identification of system performance measures
iv. Collecting and analysing data
v. Evaluation of implemented solution

2.1.1 Relationship between Transport Demand and Transit Capacity

Transport demand is expressed as the needs in mobility by a transportation mode, which is often clarified by the number of passengers and can be displayed in various time intervals and space (C. Zhou, Dai, & Li, 2013; P. Zhou, Zheng, & Li, 2012; Rodrigue, Comtois, & Slack, 2016; Xue, Sun, & Chen, 2015).

Supply in transportation refers to the transit capacity of a different mode and infrastructure offered to the users. Supply is normally defined in terms of service, operation schedule, infrastructure and network coverage ("East West Needs Study: Transport Supply and Demand (Existing and Future)," 2006; Rodrigue, Notteboom, & Shaw, 2013). Transport capacity can be further categorised into static capacity and dynamic capacity. Static capacity represents the physical space available while dynamic capacity refers to enhancement that can be made through better management and technology. The number of passengers, volume or mass transported per unit of time or space is commonly used to quantitatively express transport capacity.

Static capacity refers to the available land or space for transportation infrastructure. Static capacity will remain if there is no facility expansion in terms of allowable space. The road width and number of lanes are examples for static capacity. Dynamic capacity refers to improvement on capacity with enhanced technology, infrastructure and labour effort, often without changing the predefined physical space. This type of capacity is flexible and often undergoes improvement when the physical space becomes limited. The examples for dynamic capacity are the implemented traffic light synchronisation, double-decker bus, bus with multiple doors, etc.

The relationship between transport demand and transit capacity is inseparable, whereby passenger demand might be influenced by the capacity of transport infrastructure and services ("East West Needs Study: Transport Supply and Demand

(Existing and Future)," 2006). However, passenger demand is also dependent on external reasons, for instance, personal income, car ownership, as well as the traffic condition (Paulley et al., 2006). Thus, having a grasp on accurate data of passenger demand will help in resource allocation and operation schedule planning, which in turn will optimise transit capacity, speed, as well service reliability.

Since the needs of transportation is dynamic according to socio-economic variations and government policies, an updated and vibrant transportation management is much needed in keeping with the changes. However, recognising the factors that influence passenger demand is a difficult measure as the extent of their effects are relatively subjective and dynamic. Thus, it is important to have a proper desktop study to establish the objective and vision of an evaluation on a transportation system, as well as the limitation of the evaluation so that the identified issue can be tackled promptly.

2.2 Bus Service Operation

Bus service is one of the urban transportations that commutes along an assigned bus route equipped with prescribed bus stops that follows a published operation timetable. Its ability to provide relatively high seat capacity and advantage in cost sharing enables it to become a preferable choice in addressing the economic factors and mobility needs.

There are various types of bus operation in existence that cater to demands from commuters. These operations are named according to various applications. The types of applications that differentiate the bus operations are as below:

- Route length: Express bus, shuttle bus
- Frequency: Bus rapid transit
- Service purpose: Post bus, feeder bus
- Type of bus used: Double-decker bus

- Serving area/target: Urban bus, suburban bus, campus bus, school bus

Compared with rail systems, the bus service enjoys advantages in flexible resource allocation and route amendment by using the existing road infrastructure without the need to construct a new one. Besides, the bus service is unsusceptible to prolonged system break down as the service reliability is dependent on the vehicle itself and not the whole operation system. Moreover, the construction of a bus stop or bus lay-by is relatively cheap and easy compared to an integrated transit hub or gateway. However, buses are often professed as an inferior mode of transportation as the service performance qualities are pliant to common features like traffic congestion, weather condition, inferior bus stop facility as well as unpredictable occurrence of vehicle failure causing a degradation in transit reliability. Thus, it is crucial to evaluate the interaction between internal and external elements that govern the bus service performance (Bell, 2001).

Campus bus is a type of bus operation that serves mainly the academic campuses for the academic community. This operation aims to ease the mobility and accessibility of the campus community especially students to reach different places on campus as well as to travel between campus and a nearby public transportation interchange station or transportation hub. The main serving target group of the campus bus service is students who live on campus as they rely heavily on the service due to economic concerns (Hashim et al., 2013).

2.3 Transit Capacity, Speed, and Reliability on Transit Performance Analysis

Transit capacity, speed and reliability are the key standards to be considered in a transit performance analysis (*TCQSM*, 2013). These standards are evaluated to identify the level of efficiency and effectiveness of a transit service. The outcome of the analysis is often compared with the analysis done from the previous year to forecast the growth of passenger demand in the future. The capability to accommodate the current passenger demand is assessed to determine whether any mitigation works should be done to upgrade the service. Besides, the analysis outcome will be compared with the prescribed standards to check if the transit service meets the targeted goal or objective in the transportation master plan, often developed by the authority ("Best practices in evaluating transit performance," 2014).

Capacity, speed and reliability, these three attributes are interrelated and often influence each other. Thus, it is crucial to look particularly at the aspects or parameters that these attributes depend on. A final solution has to be reached by optimising the values of these attributes without causing an adverse effect on other transportation parameters and components.

2.3.1 Transit Capacity on Performance Analysis

Transit capacity can be distinguished as the person capacity, referring to the maximum number of passengers that can be carried past a given location during a given time period under specified operating conditions; without unreasonable delay, or restriction; and with reasonable certainty (*TCQSM*, 2013). Figure 2.1 shows the factors that influence the transit capacity and the correlation between them.

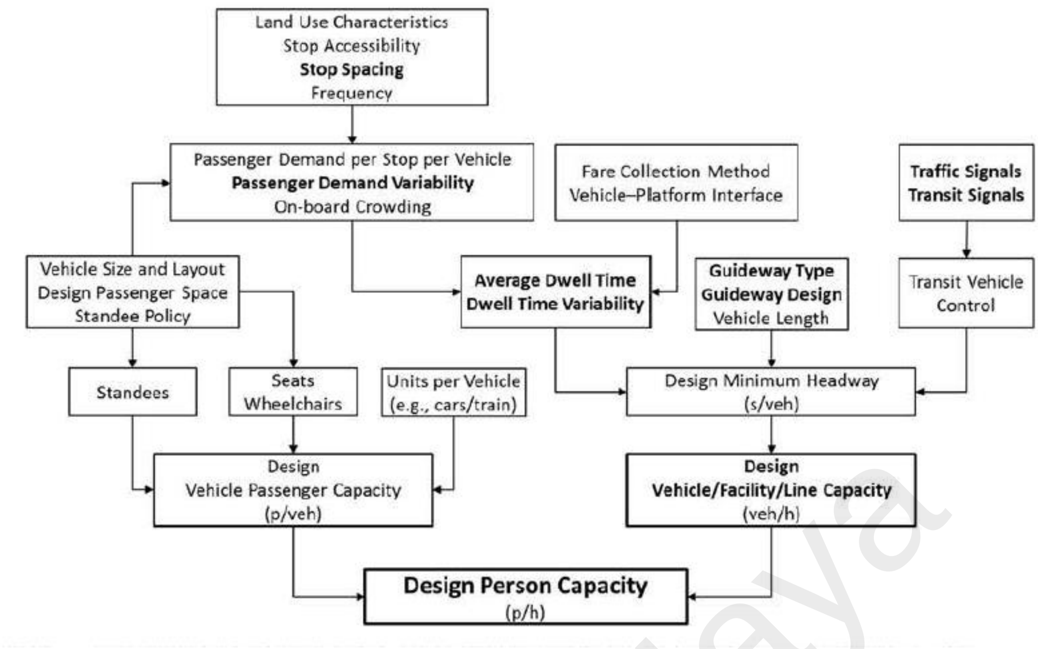

Figure 2.1: Factors influencing person capacity (*TCQSM*, 2013)

Person capacity is focused more on the study of transit capacity rather than the vehicle facility (bus facility) and passenger capacity. However, determining the vehicle capacity and passenger capacity are often necessary steps before determining the person capacity. Person capacity can also be expressed as the product of vehicle capacity and vehicle passenger capacity.

$$\textit{Person Capacity} = \textit{Vehicle Capacity} \times \textit{Vehicle Passenger Capacity} \quad (2.1)$$

The vehicle capacity of a given transit route or facility is known as the maximum number of transit vehicles that can pass through a particular location within a given time interval at a specified level of reliability (vehicles per hour). On a transit bus route, vehicle capacity is known as bus capacity which is the number of transit bus that can pass a point during a particular time period, typically in one hour. The bus capacity depends on the service headway and passenger demand variability especially during peak intervals.

The vehicle passenger capacity refers to the maximum number of passengers accommodated by a given vehicle facility, be it standees or seats available on-board. Furthermore, the size of bus and the design of the bus entrance also influence dwell time, because they affect the possibilities of a bus arriving at a stop already crowded with passengers, some of the passengers will need to make their way to and out of the door before other passengers can board.

The person capacity depends on both the number of transit buses that can pass by a certain station in an hour and the number of passengers that can be carried on those buses, the bus capacity and the passenger capacity. Consequently, the person capacity of a transit bus service must allow some slack to accommodate potential surges in passenger demand, when it is desired that virtually all passengers will be able to board the first vehicle that goes to their destination. Moreover, person capacity should reflect the number of passenger ridership that can be carried on a sustained basis day after day, considering the variations in passenger demand, traffic congestion, and other factors not under the control of the transit operator. More passengers than the scheduled person capacity may sometimes be carried, but not most or all the time.

2.3.2 Transit Speed on Performance Analysis

Transit speed determines the time needed to complete a trip according to the assigned route, which is the travel time needed by a transit service to complete a trip cycle. In the transportation system, the transit operating cost is the inverse of the passenger travel time. The higher the speed, the lower the time needed to reach a destination, which in turn will increase the operating cost needed. Thus, the balance between transit operating cost and transit speed has to be controlled wisely to attract ridership.

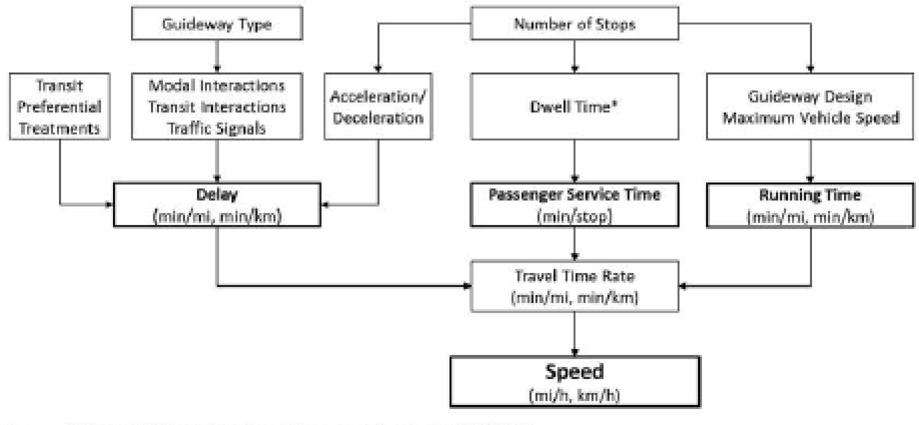

Figure 2.2: Factors influencing the transit speed (*TCQSM*, 2013)

Figure 2.2 shows that the transit speed is the combination of three main components, which are delay time, transit running time and passenger service time. Delay time is the extended service time influenced by external factors, which are caused by expected or unexpected occurrences. The more the interaction in between the external factors, the longer the transit delay time is. Transit running time is the time a vehicle spends on moving at a constant speed and acceleration, which is typically constrained by the guideway design, the characteristic of the vehicle being operated and stopping frequency, which is determined by the number of stops along the route. Passenger service time refers to the time that is needed for the vehicle to interact with the passenger, which is often expressed by the stopping time required at a planned bus stop. The time required for service is directly influenced by the dwell time which is the time taken during a stop at a bus station.

According to Transit Capacity and Quality of Service Manual (*TCQSM*, 2013), dwell time is the key factor that determines transit capacity and transit speed. The aspects relating to the dwell time at a bus stop are given as below:

i. Numbers of passenger boarding and alighting. Time taken is directly proportional to numbers of passenger served.
ii. Fare payment system. Different times are taken to complete different methods.
iii. Type and size of the vehicle. Boarding and alighting activities need lesser time when the entrance is near at-grade to ground. The number of doors affect the dispersion of passenger on-board as well as the simultaneous queuing actions at the door.
iv. In-vehicle circulation. Boarding and alighting activities are affected by the crowding on-board.

With respect to dwell time, the influencing factor can be seen from Figure 2.1. The main governing factor for dwell time is the passenger demand variability, which is the time required to serve the boarding and alighting passenger. Besides, the vehicle-platform interface directly affects the way a passenger passes through the door, which includes features like the number of doors, the width of doors, the time needed for a door to open and close, the height of platform as well as the height of steps.

2.3.3 Transit Reliability on Performance Analysis

From a passenger's view, the transit reliability is mainly related to the waiting duration of the bus's arrival at a station. It determines the passenger's choice whether to trust and continue using the transit service. It is clear that the transit frequency, transit speed and travel time directly affect the passenger's perception towards the transit reliability. The relationship between the internal and external factors that affect the transit reliability are listed in Figure 2.3.

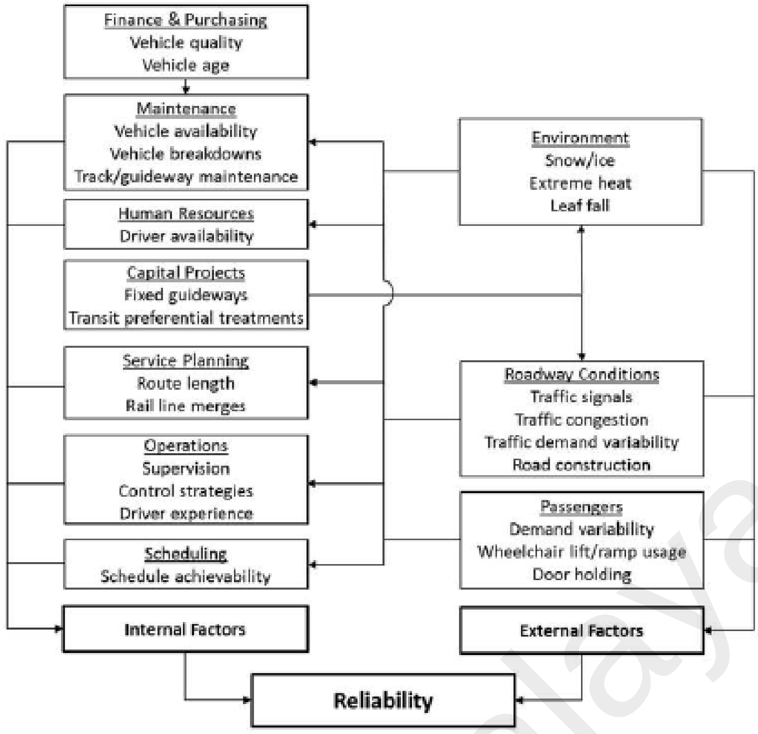

Figure 2.3: Factors influencing transit reliability (*TCQSM*, 2013)

From Figure 2.3, it can be observed that the internal factors are attributes that are under the control of the transit operator while the external factors are attributes that the transit operator is unable to control. Although there is no solution to completely prevent any unforeseen incidence, those external factors could be mitigated to reduce the impact on transit reliability.

2.4 Passenger Demand

Transit reliability is a multidimensional phenomenon in that there is no single measure that can adequately address the quality of a transit service. The most common measures used for transit reliability typically relate to the transit capacity provided in a given time period, which are trip times, passenger load, transit departure frequency, schedule adherence, etc. The usefulness of each transit reliability measure is largely determined by the service frequency, type of bus in operation and functional need (e.g., scheduling or performance monitoring). Important distinctions exist between passengers and operators in their perceptions of service quality.

Dwell time is also an important measure of transit performance. Dwell time represents the elapsed time for a bus to traverse from one location to another. Running time is an important measure of bus performance to transit providers because it serves as a key scheduling input and provides a means to monitor schedule accuracy. Running times are important to passengers because they affect their waiting time at the station and in-vehicle travel time.

Many researchers have argued that bus performance should be measured at intermediate locations along a route rather than at the route terminus because relatively few passengers are affected at terminal locations (Henderson, Adkins, & Kwong, 1990; Nakanishi, 1997; Woodhull, 1987). It is more practical for agencies to monitor transit service reliability at peak passenger load point. According to Kaufman and Smith (1990), passengers are mostly concerned with schedule adherence at their particular bus stop. Kaufman and Smith (1990) argues that each bus stop should be considered when designing schedules in order to provide the best possible service to passengers.

It is important to make a distinction between low and high frequency service when discussing transit service reliability. For routes characterised by infrequent service or those with timed transfers, schedule adherence is the most important reliability measure. Passengers attempt to time their arrivals with that of the bus based upon a given probability of missing the departure (Turnquist & Bowman, 1980). Under these circumstances, average wait times are less than one-half of the scheduled headway. High frequency service is typically defined as bus service that operates at headways of ten minutes or less (Abkowitz, Eiger, & Engelstein, 1986; Abkowitz & Tozzi, 1987; Nakanishi, 1997; Wilson, Nelson, Palmere, Grayson, & Cederquist, 1992). For routes that operate at high frequencies, headway variability is the most important reliability indicator. The aggregate wait time of passengers is minimised when buses are evenly spaced. Because passengers do not find it advantageous to time their arrivals with that of the schedule on high frequency routes, an assumption of random passenger arrivals is valid.

It is well known that transit service varies over time, space, direction, and by route typology (Abkowitz & Engelstein, 1983, 1984; Stopher, 1992; Strathman & Hopper, 1993). Locations such as transportation hub and faculties' buildings are often associated with large patronage volumes. A considerable amount of variation in demand exists on bus routes over the course of a single day. The highest levels of ridership coincide with the concentration of work trips during peak time periods of operation. Demand on bus routes is not directionally balanced during the morning and afternoon time periods. Passenger demand is greater in the inbound direction during the a.m. peak time period and lighter in the outbound direction (Abkowitz & Engelstein, 1983; Hartgen & Horner, 1997). The opposite holds true for travel during the p.m. peak time period. Peak period demand on crosstown routes is typically not differentiated by direction.

2.5 Dwell Time

Travel time is a parameter to the efficiency and reliability level of a bus transit service. The time taken to complete the whole trip consists of delay, passenger service time and running time (Oi, 2017). Passenger service time, which is the summation of all dwell times at stations in a bus trip, has the most direct impact on the travel time, affected directly by the activity of passenger at the entrance. The model equation for travel time is as below:

$$\textbf{Travel Time} = f(\textbf{DT}, \textbf{MT}, \textbf{D}) \qquad \textbf{2.2}$$

where:

DT : dwell time (s);

MT : moving time (s);

D : delay (s).

Dwell time of a bus at each station is often focused on as an indicator for efficiency and reliability of a bus transit service (Arhin et al., 2016; Bian, Zhu, Ling, & Ma, 2015; Inta & Muntean, 2015; Ólafsdóttír, 2012). Dwell time with high variability contributes the most variation on the travel time (Oi, 2017). The application of the linear regression model on a bus service is able to study the relationship between dwell time and a few affecting variables contained within the service. The outcome of the analysis is useful for prediction of transit performance with proper application of transit demand, which subsequently leads to a reliable bus schedule planning (Inta & Muntean, 2015). Transit Capacity and Quality of Service Manual (*TCQSM*, 2013) proposes a function for the calculation of vehicle's average dwell time to number of boarding and alighting passengers:

$$\textbf{Travel Time} = f(\textbf{DT}, \textbf{MT}, \textbf{D}) \qquad \textbf{2.3}$$

$$DT = x_a t_a + x_b t_b + t_c \qquad \textbf{2.4}$$

where x_a and x_b denote the number of alighting and boarding passengers of bus respectively, while the parameters t_a and t_b express the time taken per passenger for alighting and boarding respectively. t_c represents the time taken for the doors to open and close.

The equation above is widely used due to its simplicity/purity and does not include other factors of public transportation mode, such as type of vehicle used, location of station, passenger load in bus, weather, traffic condition and time of the day (Chen, Liu, Xia, & Chien, 2004). The impact of overcrowding and different types of vehicles used was demonstrated by Fritz (1983), whereas Szplett and Wirasinghe (1984) and Wirasinghe and Szplett (1984) investigated the impact of passenger distribution waiting at a stop. They mentioned that the dwell time is affected by the location of a stop. For example, the station in a suburb or Central Business District (CBD) has longer dwell time than other stations. Meanwhile, Lin and Wilson (1992) proposed linear and non-linear dwell time models to take into account the number of boarding and alighting passenger, passenger load factor (PLF), and the number of vehicles. Currie, Delbosc, Harrison, and Sarvi (2013) conducted a survey to establish a positive correlation between dwell time and PLF.

Daamen, Lee, and Wiggenraad (2008) established the impact of a vertical and horizontal gap on the passenger flow rates, while Fernández, Zegers, Weber, and Tyler (2010) focused on the effect of horizontal gap and door width with dwell time. They concluded that a small gap of vehicle entrance door slows down the passenger flows and they constructed dwell time models for use in metro stations and bus stops.

Most of the previous research on dwell time are less focused on the effects of PLF. Rajbhandari, Chien, & Daniel (2003) differentiate the effect of standing and sittings passengers on bus dwell time. Fletcher and El-Geneidy (2013) are the seldom researcher that focus on the onboard crowdedness with percentage of passenger load, which is similar to PLF. Glick and Figliozzi (2019) use log-linear and quantile regression to predict bus dwell time but onboard crowdedness is not considered in the dwell time model. This research will go beyond by identifying the relationship between dwell time and the bus

PLF is useful to improve the bus transportation network and can assist the operator in managing the bus schedule. The PLF influences other determinants of dwell time, which causes a complex relationship between the PLF and the bus dwell time. In this study, the effect of dwell time specifically on PLF is introduced whereby the dwell time model consisting of variables such as number of boarding and alighting passenger, type of bus and location of stops is developed.

The PLF is divided into three categories according to the degree of intensity and a dwell time model is developed for each PLF category. The three different models show the interaction between dwell time and other determinants at different levels of PLF.

2.6 Bus Timetable Optimization

The current literature on bus timetable optimisation mainly focuses on considering bus transit reliability, service quality and travel time. Salicru, Fleurent, and Armengol (2011) generated run-time values by using analytical development and microsimulations to improve the bus operating process. Y. Yan, Meng, Wang, and Guo (2012) designed a robust optimisation based on Monte Carlo simulation to minimise the sum of random schedule deviation and its variability. Xue et al. (2015) considered minimising bus travel time and examined the optimal stopping criteria for limited-stop bus services. Vissat, Clark, and Gilmore (2015) designed a stochastic model to predict bus arrival times. The model is analysed by using stochastic simulation and proposed a timetable which improved the bus service, punctuality and reliability. Wu, Yang, Tang, and Yu (2016) studied the re-planning issue of a bus network timetable, taking into consideration headway-sensitive passenger demand, uneven headway, service regularity, and flexible synchronisation. Arhin et al. (2016) studied factors that influence bus transit reliability by using non-linear programming to improve the efficiency of a bus timetable.

Furthermore, lots of previous researches have also focused on bus timetable design problems with consideration for passenger waiting time at a bus station. Tong and Wong (1999) presumed the waiting time and in-vehicle time are random variables and used Monte Carlo Simulation to solve the dynamic transit assignment problem based on a mass transit network. S. Yan, Chi, and Tang (2006) established a model to minimise the operation cost with consideration to passenger demand variation. Two heuristic algorithms were developed to solve the model by using simulation technique, coupled with link-based and path-based routing strategies. Amin-Naseri and Baradaran (2014) developed a discrete simulation model to evaluate the efficiency of an estimation average waiting time formula. The accuracy of the proposed formulations is better than the existing one. Parbo, Nielsen, and Prato (2014) proposed a timetable optimisation model by using Tabu Search algorithm to minimise the passenger waiting time when transferring to or from a bus. Wu, Tang, Yu, and Pan (2015) designed a Genetic Algorithm (GA) with local search to solve the minimisation problem on total waiting time for transferring passengers, boarding passengers, and through passengers.

Furthermore, most of the existing studies on timetable optimisation models researched on a single type of vehicle and a few considered hybrid vehicles. D. J. Sun, Xu, and Peng (2015) constructed three different models for hybrid vehicles, big vehicles, and small vehicles to tackle the variation in passenger demand in order to propose an optimal bus timetable. The results showed that the hybrid vehicle sized model is the best model among all three models in terms of total time and total cost. But the study did not take the vehicles' capacity into consideration.

The bus timetable is designed with even departure times where the bus service is not efficient when the passenger demand varies (Ceder, Hassold, Dunlop, & Chen, 2013). The efficiency of a transit bus service is challenging due to the fluctuation of passenger demand throughout. Furthermore, resource wastage occurs frequently during off-peak hours due to oversupply of person capacity. Researchers also paid less attention on the effects of dwell time on the efficiency of a bus timetable.

2.6.1 Modified Version of Li's Algorithm

The bus timetable optimisation problem from either the bus operators' perspectives or passengers' perspectives has drawn great attention in recent years. Li, Du, Ma, and Shang (2018) had developed a bi-objective optimisation with the consideration of the bus operators' and passengers' perspectives. GA is used to minimise the travel time and passenger waiting time. However, this simulation optimisation analysis has a number of limitations. One major drawback of this approach is that the maximum passenger capacity of a bus is not take into account. Furthermore, only one bus type is considered in this timetable optimisation.

The simulation of bus timetable optimisation in this study uses Li's (2018) model with a few modifications. Li et al. (2018) used GA to solve the bi-objective optimisation to minimise total travel time and passenger waiting time; whereas the bi-objective function in this study is aimed at minimising total dwell time and passenger waiting time. The constraint of passenger load in a bus is also added in this study. Furthermore, the bus optimisation in this study can take the use of multiple bus types into account. The bus timetable optimisation model is tested and evaluated using real-life data.

CHAPTER 3: METHODOLOGY

This research aims to study the transit performance of the University of Malaya (UM) campus bus service by focusing on the relationship between the passenger demand and the person capacity of the bus service. The satisfactory level of the campus society with regards to the quality and facilities of the campus bus service are identified through a questionnaire. Furthermore, the service performance of the on-campus bus routes is analysed using various measures, such as passenger load factor and peak hour factor. The analysis is aimed at highlighting the adequacy between distribution of passenger demand and person capacity. In addition to the passenger demand and person capacity analysis, a study is also done to identify the dwell time determinants by providing equations that describe the relationships between dwell times and dwell time factors. Dwell time determinants of the campus bus service are identified by using multiple regression analysis. A timetable is proposed to develop a sustainable campus bus transportation system by using a simulation of bus timetable optimisation. Figure 3.1 shows the research framework of this research study.

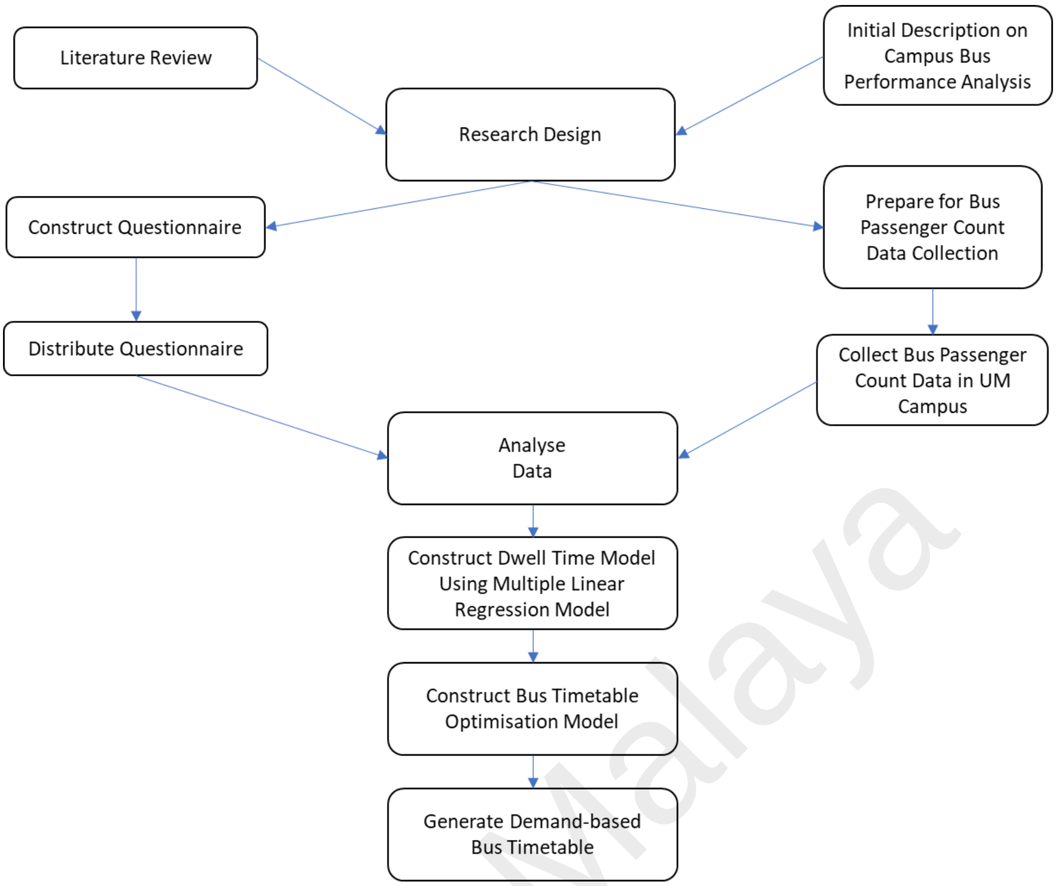

Figure 3.1: Research framework

3.1 Research Design

This research is aimed at studying the relationship between passenger demand and the person capacity of the campus bus service. Thus, it is crucial to first study the relationship between transit demand and capacity. Transit demand in this study can be used in the form of passenger ridership. Ridership is crucial and can be defined as passenger demand on the transit bus service. This is the parameter that refers to the peak hours of the bus service. The passenger demand is needed for comparison with the current peak hour to evaluate the adequacy of the bus operating timetable.

In terms of transit speed and reliability, regression modelling was chosen as the analysis technique. Regression modelling is a statistical method to identify the relationship among variables. A regression model with one dependent variable and more than one independent variable is known as a multiple regression model (Uyanık & Güler, 2013). In addition, to detect the possible imperfection of the campus bus service, the comments from passengers are studied and suggestions are made to overcome the weakness of the bus service infrastructure. The performance of the current bus timetable is analysed and bus timetable optimisation is used to generate a new timetable. The suggested new bus timetable should improve the riding experience of passengers.

3.2 Questionnaire Survey

The questionnaire survey aims to identify the satisfactory level of UM commuters of the campus bus service, based on their riding experience. The order of questions is arranged from the more general questions to the more specific. The questionnaire is divided into three parts. The first part covers the demographics of the respondents. The second part is on their travel behaviour, daily transportation mode and willingness to change to the public transportation mode. The final part is on their satisfaction of the facilities and service of the current campus bus service. Open-ended questions were included in the questionnaire to collect personal comments and recommendations from the respondents.

The questions in the survey was designed to be easy to understand by UM students from different academic background. The questionnaire was distributed to Civil Engineering final year students for pilot study to collect feedback on this questionnaire design. The questionnaire was conducted by random sampling through Google Forms platform and the link was sent to all student emails, including undergraduate and postgraduate students.

The sample size determination method by Krejcie and Morgan (1970) is used. The sample size was determined based on the equation below:

$$s = \frac{\chi^2 NP(1-P)}{d^2(N-1) + P(1-P)} \quad 3.1$$

where:

s = required sample size.

χ^2 = the table value of chi-square for 1 degree of freedom at the desired confidence level (3.481).

N = the population size.

P = the population proportion (assumed to be 0.50 since this would provide the maximum sample size).

d = the degree of accuracy expressed as a a proportion (0.5).

Table 3.1: Statistical precision of estimates

Population Size	Confidence Level	Margin of Error	Sample Size
17580	95%	5%	376

Table 3.1 shows the statistical precision on sample size estimation. To achieve the result with a 95% confidence level and 5% margin of error, the minimum number of questionnaire respondents for a population of 17580 students is a sample size of 376 respondents. With a minimum 376 samples, it is predicted that the questionnaire result has 95% accuracy to represent the population of students in UM campus with $\pm 5\%$ error.

From this survey, the feedback from passengers on the satisfaction level of the bus service is collected relative to the punctuality, crowdedness of bus, waiting time, travel condition, and other aspects. The passengers perception on the quality of the service as well as the bus facilities are covered in the questionnaire. The bus service satisfaction level of respondents collected from the questionnaire was analysed and the performance of the UM campus bus service was measured. The outcomes were analysed by descriptive statistics, which include the presentation of graphs, tables and general discussion. This questionnaire aims to review any signal on the weakness of the campus bus service. The questionnaire is as shown in Appendix A.

3.3 Passenger Demand Distribution Analysis

3.3.1 Passenger Count Data Collection

One of the main objectives of this project is to identify the bus service performance of on-campus bus routes in the UM Campus, as well as to analyse the passenger demand and person capacity. The analysis was based on two empirical datasets collected manually, bus trip time dataset and bus passenger count dataset.

This study is focused only on the on-campus bus performance for the typical daily trip, when lectures and tutorial classes are normally carried out. The data collection was not conducted on Mondays, Fridays and weekends as the outcome may not be representative of the normal daily passenger ridership. Passenger count data collection was done on Bus Route A and Bus Route B. This survey does not account for bus routes that travel outside the UM campus, which are Bus Routes C, D and E, as according to the research scope. The number of passengers boarding and alighting at every station and trip were collected by conducting a passenger count survey. The operation timetable and bus stations served by the on-campus bus routes are shown in Figure 3.2 and Figure 3.3 respectively.

SHUTTLE BUS OPERATION SCHEDULE (ROUTE A & B / IN CAMPUS)

[MONDAY - FRIDAY]

TRIP	OPERATION TIME	
	FROM API	FROM UMS
1	7.20am	7.35am
2	7.40am	7.55am
3	8.00am	8.15am
4	8.20am	8.35am
5	8.40am	8.55am
6	9.00am	9.15am
7	9.20am	9.35am
8	9.40am	9.55am
9	10.00am	10.15am
10	10.20am	10.35am
11	10.40am	10.55am
12	11.00am	11.15am
13	11.20am	11.35am
14	11.40am	11.55am
15	12.00pm	12.15pm
16	12.20pm	12.35pm
17	12.40pm	12.55pm
18	1.00pm	1.15pm
19	1.20pm	1.35pm
20	1.40pm	1.55pm
21	2.00pm	2.15pm
22	2.20pm	2.35pm
23	2.40pm	2.55pm
24	3.00pm	3.15pm
25	3.20pm	3.35pm
26	3.40pm	3.55pm
27	4.00pm	4.15pm
28	4.20pm	4.35pm
29	4.40pm	4.55pm
30	5.00pm	5.15pm
31	5.20pm	5.35pm
32	5.40pm	5.55pm
33	6.00pm	6.15pm
34	6.20pm	6.35pm
35	6.40pm	6.55pm
36	7.00pm	7.15pm
37	7.20pm	7.35pm
38	7.40pm	7.55pm
39	8.00pm	8.15pm
40	8.30pm	8.45pm
41	9.30pm	9.45pm
42	10.30pm	10.45pm
43	11.30pm	-

[SATURDAY & SUNDAY / PUBLIC HOLIDAY / SEM. BREAK]

TRIP	OPERATION TIME	
	FROM API	FROM UMS
1	8.00am	8.15am
2	9.00am	9.15am
3	10.00am	10.15am
4	11.00am	11.15am
5	12.00pm	12.15pm
6	1.00pm	1.15pm
7	2.00pm	2.15pm
8	3.00pm	3.15pm
9	4.00pm	4.15pm
10	5.00pm	5.15pm
11	6.00pm	6.15pm
12	7.00pm	7.15pm
13	8.00pm	-

Reference:

(shaded)	Break for Friday Prayer
API	Academy of Islamic Studies
UMS	UM Central

* Depends on current traffic situations

Figure 3.2: UM campus bus timetable - Bus Route A and B

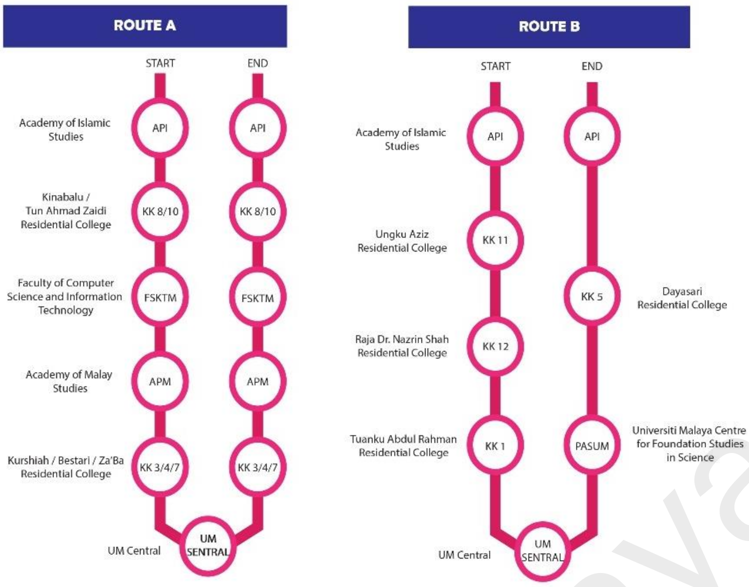

Figure 3.3: Bus stations for Bus Route A and B

The procedure to collect bus passenger count data in the Transit Capacity and Quality of Service Manual (*TCQSM*, 2013) consists of the following steps to collect field data to estimate passenger service times:

i. From a position on the transit vehicle, record the stop name at each stop.
ii. Record the time that the vehicle comes to a complete stop.
iii. Count and record the number of boarding and alighting passengers.
iv. When the passenger flow stops, count and record the number of passengers on board.
v. Record time when vehicle starts to move.

The data used in this study were collected through manual bus passenger count methods with assigned enumerators. The enumerators recorded the number of passengers boarding and alighting at each station, as well as the bus dwell time. An enumerator is assigned to a door on the bus to collect the required data. The passenger count data sheet used to record the collected data is shown in Appendix B and Appendix C.

The passenger count data survey was carried out from 8:00 a.m. to 7:00 p.m. during the periods of 28th to 29th September and 1st to 15th November 2016. A total of 138 bus trips were logged with a total of 6960 ridership recorded; 55 bus trips were logged with 2922 passengers for Bus Route A, 45 bus trips were logged with 2991 passengers for Bus Route B, and 38 bus trips were logged with 1047 passengers for Bus Route E. Each observation reports the number of boarding passengers, number of alighting passengers, and the dwell time of a stop. The type of bus used is also recorded before every trip starts. In addition, the passenger load factor (PLF) is calculated later for each stop.

3.3.1.1 Mobile phone counter application

A mobile phone application named Advanced Tally Counter was used to record the number of passengers boarding and alighting at every station for all bus routes. The time for counting action and coordinated location data were logged and exported in csv. file type. This application was utilised by the enumerators to ease their counting work and is able to count boarding and alighting passengers simultaneously, on top of keeping track on the movements to tally the numbers on the passenger count survey sheet. The data also served as the backup for any missing data for bus dwell time. Figure 3.4 shows the interface of the Advanced Tally Counter mobile phone application.

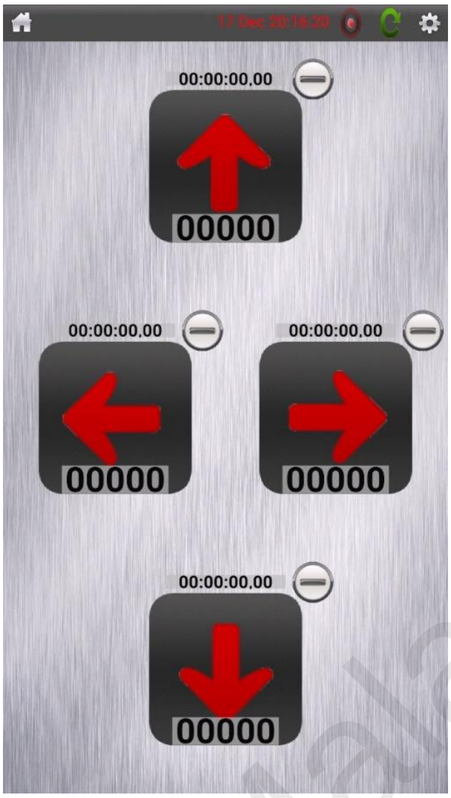

Figure 3.4: Interface of Advanced Tally Counter mobile phone application

An enumerator was assigned to each door of the bus for every single trip within the 11-hour passenger count survey. The enumerator counted the number of boarding and alighting passengers with this mobile phone application and the final figures for each stop were recorded on the passenger count survey sheet after the counting was done. Besides recording the number of boarding and alighting passengers, the enumerator also observed any unusual situation that took place at the bus stops during the trip, which will then be utilised in the performance analysis.

3.3.1.2 GPS Travel Log mobile phone application

GPS Logger for Android, a global positioning system (GPS) mobile phone application, is also installed in the mobile phones of the enumerators to log the bus movement throughout the whole bus trip. This GPS app is created by Mendhak and downloaded from Google Play Store. GPS Logger is used to record the bus location data and distance travelled. The signal frequency was set to 1 second per signal in order to have accurate bus GPS travel data.

The bus location data which contains time, latitude, longitude, and speed of bus are saved in gpx. file type and converted into csv. file type. The data is useful in studying the travel time as well as dwell time of every bus stop at full length within the survey period. Figure 3.5 shows the interface of the GPS Travel Log mobile phone application.

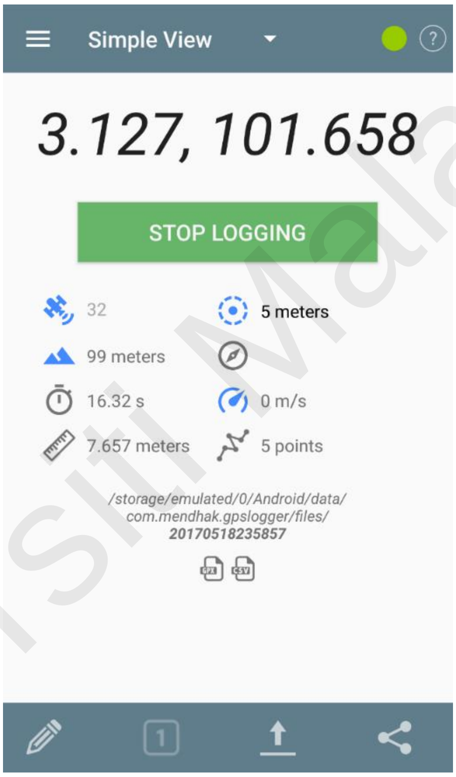

Figure 3.5: Interface of GPS Travel Log mobile phone application

3.3.2 Passenger Demand and Person Capacity Analysis

The number of boarding passengers at each station on every bus trip throughout the observation period are extracted from the passenger count data and named as the passenger ridership. The hourly average passenger ridership is calculated and analysed with the corresponding seat capacity recorded, to identify the PLF, which is the index of the bus on-board occupancy. The average passenger ridership is plotted on a graph and forms the passenger demand distribution, which is the hourly passenger demand throughout a day during the 11-hour observation period. The current peak hours with higher person capacity than off-peak hours and the passenger demand distribution are compared to study the adequacy and accuracy of the designed person capacity in coping with the passenger ridership.

PLF is used to study the fitness of the bus passenger capacity in handling the passenger demand. Bus trips with high ridership but with PLF value of less than or equal to one means that the vehicle passenger capacity is able to handle the passenger demand at the specific time period. If a bus trip has low ridership but has PLF average hourly value of more than one, this means that the vehicle passenger capacity is not enough to handle the passenger ridership on a specific trip or time period. This situation shows that the usage of bus facilities such as the type of bus in operation is not well planned.

The passenger demand variation is attributable to the timing of passenger demand whereby high passenger demand is around 10 to 20 minutes to the exact hour, in order to arrive at the destination from the desired departing time. Another reason for the passenger demand variation may be due to the variation in a passenger's activities on any given day which would result in the passenger taking the transit bus at different times on different days. All of these variations have implications on the level of on-board crowding, which can be detected by PLF, as will be discussed in section 4.2.3. Although the person capacity is assigned to accommodate the passenger demand during peak hours, the overcrowded situation may still happen due to uneven demand during the identified peak hour (*TCQSM*, 2013).

The peak hour factor (PHF) concept is used to express the demand variation within the peak hour. The PHF in this study is calculated by dividing the demand in peak hour to three times the demand in peak 20 minutes as shown in the formula below.

$$PHF = \frac{Demand\ in\ hour}{3 \times Demand\ in\ 20\ minutes} \quad \textbf{3.2}$$

In the Transit Capacity and Quality of Service Manual (*TCQM*, 2013), demand during the peak 15 minutes to an hour is used to calculate the PHF instead of using demand during the peak 20 minutes to an hour. However, the 20-minute interval is used here because the bus trips in this study depart on the multiple of 20 minutes in an hour for the off-peak period and a multiple of 10 minutes in an hour for peak period. Therefore, the value of PHF is 1.00 indicating that the passenger demand is even in each 20-minute period of the hour, while PHF with a value of 0.33 shows that all the passenger demand occur in one 20-minute period.

3.4 Dwell Time Analysis with Multiple Linear Regression Modelling

Dwell time is defined as the time spent for stopping at the bus station, and serves as one of the important parameters in transit reliability as discussed earlier in Section 2.5 (Arhin et al., 2016; Bian et al., 2015; Inta & Muntean, 2015; Ólafsdóttír, 2012). Dwell time contributes the most to the travel time variation, and subsequently, to the reliability of the transit service. The factors that contribute to the bus dwell time will be identified by using multiple linear regression analysis. The outcome of the analysis is useful to predict the transit performance with proper application of transit demand, which will lead to a reliable bus timetable planning (Arhin et al., 2016). Hence, the multiple linear regression model is used to precisely express the relationship between the affecting variables and dwell time. A comparative analysis will be done among different bus dwell time models to study the dwell time factors on service reliability.

Multiple linear regression analysis is used to study the relationship between a continuous dependent variable and several independent variables (regressors) from observed or empirical data (Uyanık & Güler, 2013). In this research, dwell time is the dependent variable whereas the factors of dwell time are independent variables. The ordinary least squares (OLS) estimator is used to estimate the coefficients of the regressors in the regression model. The OLS estimator is based upon six critical assumptions that must be satisfied in order to achieve the best linear unbiased estimator (BLUE) for the model (Miles & Shevlin, 2001). The dependent variables is not normally distributed, yet the distribution of standardised residuals for all the dwell time models are closed to normal distribution $N(0,1)$.

3.4.1 Assumptions of Ordinary Least Squares (OLS)

Regression is a powerful analysis that can analyse multiple variables simultaneously to model a complex research problem. However, if the assumptions of the OLS estimator are not satisfied, the model might not provide an accurate and reliable result (Wooldridge, 2012). OLS is the most common estimation method for linear models. As long as the regression model satisfies the OLS assumptions, the coefficients of the independent variable in the model is the best possible estimator to represent the relationship between the dependent variable and regressor (Wooldridge, 2012). Many of these assumptions describe properties of the error term. Instead of using the error term, the residual is used to check the assumptions (Wooldridge, 2012). The residual is the difference of the observed value from collected data and the fitted value from the model. The most likely problems with regression models pertain to multicollinearity, heteroskedasticity and autocorrelation of residuals.

The first OLS assumption is that the coefficients and error term in the regression model are linear. Each of the independent variable has a linear correlation with the dependent variable. There are no prior theoretical reasons for believing that the expected relationships between the dependent variables and each of the independent variables are non-linear. Scatter plot graphs were drawn for the dependent variable with each independent variable showing these relationships to be either linear or non-linear in nature. To satisfy this assumption, the dwell time regression model must fit the linear pattern as per the dwell time equation in Section 2.5.

The second OLS assumption is that the error term of the regression model has a population mean of zero. This assumption is to verify that all the coefficients are unbiased estimators. The error term accounts for the variation in the dependent variable that the independent variables do not explain. If the mean of the error term is non-zero, this means that part of the error term is predictable and hence, the constructed model is biased. For an unbiased regression model, the values of the error term should be random and scattered on a residual scatter plot.

The third OLS assumption is that all independent variables in the model are uncorrelated with residual. This assumption is also referred to as exogeneity. Violating this assumption causes the coefficient to be biased and inaccurate. If an independent variable is correlated with the error term, the independent variable is used to predict the error term instead of the dependent variable, which violates the unpredictability and randomness of the error term. Scatter plots of the residual with each independent variable is used to validate the assumption. All the plots of independent variables with residual should look trendless and random.

The fourth OLS assumption is that all the error terms are uncorrelated with each other. The error terms that are predictable is known as autocorrelation. All error terms should not be predicted by the adjacent error terms. For instance, if the error term increases systematically from the previous error term, it shows an existing trend and is able to predict the following error terms, which is a positive correlation among errors. If the subsequent error term is more likely to show an opposite sign, this shows a negative correlation. This assumption can be observed by plotting the residuals in the sequence that the data were collected. The scatter plot of residuals with the collected data sequence should look random. Moreover, the Dublin-Watson test is also used to detect the autocorrelation problem. The error terms are uncorrelated with each other if the value of statistic is within [1.5, 2.5].

The fifth OLS assumption is that the variance of the error terms should be homoskedastic, whereby they do not change within the range of all observations. If the variance is inconsistent, heteroskedasticity or unequal variance occurs in the model. Heteroskedasticity refers to the problem of a non-constant error variance among the observations. According to Crown (1998), if the estimated coefficients are statistically significant despite the presence of heteroskedasticity, then there is little need for correction. The consequence of ignoring heteroskedasticity is that the regression OLS coefficients are invalid (Wooldridge, 2012). A simple visual inspection for heteroskedasticity of data can be performed by plotting the standardised residuals against the dependent variable. If homoskedasticity occurs, the spread of the standardised residuals will look consistent and parallel with x-axis between [-4, 4].

Assumption six of OLS is that all independent variables are not perfectly correlated with each other. Perfect correlation among independent variables should be avoided, whereby two independent variables have a Pearson's correlation coefficient of +1 or -1. The OLS estimator fails to distinguish one variable from the other when they are perfectly correlated. However, OLS regression models with imperfect but strong relationships between the independent variables are allowed and this condition is known as multicollinearity.

Multicollinearity is often a serious problem in regression models. If two or more independent variables are found to be highly correlated, then it is difficult to separate out the effects of each of the variables on the dependent variable. A model with multicollinearity problem shows that the p-value of coefficients may be significant but in fact, they are insignificant. The model is still valid and fulfils other OLS assumptions. It is believed that multicollinearity does not exists among the dwell time determinants in the transit service reliability models. This is because there is little theoretical overlap between the independent variables, such as number of boarding passengers and PLF.

Variance inflation factors (VIF) is used to indicate the presence of multicollinearity among the independent variables. The presence of severe multicollinearity in a multiple linear regression model will cause the estimates to be very sensitive to minor changes, making it difficult for interpretation. Multicollinearity can cause the coefficients to switch signs and make it more difficult to specify the correct model. A VIF value which is greater than five indicates a reason to be concerned about multicollinearity.

3.4.2 Validation of MLR Model

The general dwell time model is constructed using the multiple linear regression model as shown below (Washington, Karlaftis, & Mannering, 2010; Wooldridge, 2012):

$$Y = \beta_0 + \beta_i X_i + \cdots + \varepsilon \qquad \textbf{3.3}$$

where Y is the dwell time of bus, β_0 is the constant term, β_i denotes the coefficients to be estimated for $i = 1,2, \ldots, \rho$, ρ is the maximum number of independent variables considered, and ε is the disturbance term for the dwell time.

3.4.2.1 Significance test on the overall regression model

The null hypothesis of the regression model shows that there will be no significant prediction of bus dwell time by using the number of boarding and alighting passenger, transportation hub, bus type and PLF. The F-test is used to identify the overall significant level of the model, whether the regression model provides a better fit to the data than a model without independent variables (null hypothesis rejected) (Wooldridge, 2012). The independent variables in the regression model is significant if the p-value of the F-statistic is < 0.05, which means the data provide enough evidence to conclude that the regression model fits the data with the independent variables included. If the result of the F-test is statistically significant, the regression model can predict the bus dwell time better/more accurately than by using the mean value.

3.4.2.2 Significance test on single independent variable in the model

The coefficients in a regression model describe the mathematical relationship between each independent variable and the dependent variable. The p-values for the coefficients indicate whether the relationship is statistically significant or not. The residual plot is used to ensure that the estimators are unbiased after fitting in a regression model, which also means that all the independent variables are significant in the model. Bearing in mind that there is no point in having any independent variable which is not significant in this model, there may be a need to reconsider whether to drop and redo the regression analysis.

The p-value helps to determine whether the relationships from the observation sample also exist in the larger sample size. The p-value of each independent variable tests the correlation with the dependent variable. If there is no correlation, the dependent variable is not affected by the changes in the independent variable. In other words, there is insufficient evidence to conclude that the independent variable has an effect on the dependent variable at the population level. If the p-value is significant, the sample data has enough evidence to prove that this variable is statistically significant and the changes in the independent variable are associated with changes in the dependent variable.

3.4.2.3 Best subset regression analysis

Best subset regression analysis is a method to determine the best combination of independent variables that generate the model with the highest explanatory power on the dependent variable (Wooldridge, 2012). The best subset regression analysis is an automatic variable selection procedure to assess the set of independent variables. The best subset regression presents more information that is potentially valuable compared to other variable selection method (Wooldridge, 2012). Best subset regression fits all possible models and lists out some of the best models based on adjusted R-squared ($\overline{R^2}$) and Mallows' C_p. $\overline{R^2}$ and Mallows' C_p are used to compare the models and determine the best model from the list (Mallows, 1973).

R-squared (R^2) measures the strength of the relationship between the model and the dependent variable (Wooldridge, 2012). However, the R^2 value increases when more independent variables are added in the model and it never decreases. A model with many independent variables might lessened the ability to make predictions and this condition is called overfitting the model. Adjusted R-squared is a modified version of R-squared that compares the explanatory power of regression models with different numbers of independent variables. An under-specified model (model that is too simple) can produce biased estimates and an over-specified model (model that is too complex) is more likely to reduce the precision of coefficient estimates and predicted values (Wooldridge, 2012). Among the models in subset regression analysis, a model with the highest value of $\overline{R^2}$ has the optimum number of independent variables. Hence, $\overline{R^2}$ is used instead of R^2 to determine the optimum number of independent variables in a model.

Mallows' C_p is also used to identify the best model for best subset regression analysis. The best model with optimum number of independent variables is the model with the lowest C_p value approximately equal to p, where $p = 1 +$ number of independent variables. Mallows' C_p is used to choose between multiple regression models with the optimum number of independent variables in the model. Mallows' C_p compares the precision and bias of the full model to models with a subset of the independent variables. The best model is the model with the smallest Mallows' C_p value and closest to the number of independent variables in the model plus the constant (p). A small Mallows' C_p value indicates that the model is relatively precise (has small variance) on its estimation of coefficients and prediction of dependent variable.

3.4.3 Others MLR Issues

Data filtering has been conducted during regression analysis to study the impact of extreme observations and identify the limit of dwell time. Specifically, only the observations with dwell time values of less than 180 seconds are used for analysis. Dwell time values that are more than three minutes are beyond the normal operational values and they reduce the level of significance of the result in this research, and hence, are excluded. All bus trips share a same departure and end station. When a bus reaches its last station of a trip, all passengers are free to alight and board the bus. When the next bus trip departure time reaches, only then will the bus close its doors and depart. Hence, the observations of the first and last stations are omitted. Furthermore, extreme observations such as outliers, influences, and leverages were determined and excluded after conducting statistical tests such as Cook's distance and hat matrix. Inclusion of these extreme observations will affect the data distribution and reduce the accuracy of further analysis (Miles & Shevlin, 2001). Finally, a total of 538 observations are included in the analysis after all the filtering. Minitab, a statistic software is used to perform the regression analysis.

3.4.4 Overall Flow in the Dwell Time Analysis Part

The first part of the dwell time analysis involves the modelling of dwell time using multiple linear regression to identify the effects of the number of boarding and alighting passenger as mentioned in Section 2.5. The second part of the analysis involves the modelling of dwell time using multiple linear regression to identify the effects of bus type, type of station, and the number of boarding and alighting passenger. The third part of the analysis is the investigation of dwell time patterns on different levels of PLF.

3.5 Bus Timetable Optimisation

The variation of passenger ridership demand distribution is one of the issues in urban transit operation research and bus operating efficiency (Doust, 2014; Semeida, 2014). Bus resource wastage at off-peak hours and overloaded buses at peak hours are common phenomena, which leads to doubts in the efficiency of the bus timetable (D. Sun, Peng, Shan, Chen, & Zeng, 2011; Xue et al., 2015). Bus timetable optimisation is an important task for transportation researchers to identify these problems and provide an optimal bus timetable. For bus operators, it is important to determine an optimal timetable with appropriate intervals between trip departure times for a bus route to adjust to the demand fluctuation. For bus passengers, it is important to minimise the waiting time at the bus station.

The bus timetable optimisation model by Li et al. (2018) is used in this study with some modifications to suit this study. Bi-objective optimisation model is used to minimise the total dwell time for all trips along the bus route and the total waiting time for all passengers at all stations, in which the dwell times are calculated using the dwell time model generated by regression analysis from this study. The simulation of the bus timetable optimisation used in this study is a nonlinear integer programming, and genetic algorithm is used to propose an optimal bus timetable.

3.5.1 Assumptions, Notations and Constraints of Optimization Model

Simulation of the bus timetable optimisation is used to generate an optimal bus timetable with consideration for the bus departure times and bus type used simultaneously. The bus operator needs to determine the departure timetable and the corresponding bus type used for each bus trip. In the decision-making process, the passenger ridership distribution and the level of onboard crowdedness in the bus must be considered simultaneously. The goal of the bus operator is to minimise the total number of trips and maximise the passenger volume on each bus trip, whereas the passengers want to minimise their waiting time at the bus station.

3.5.1.1 Assumptions

In order to formulate this problem briefly, the following assumptions are made:

i. The operation parameters (i.e., speed, acceleration, etc.) are assumed to be equal for all vehicle size buses in the study;
ii. The demand of bus passengers will not be affected by the frequency of the buses;
iii. There is no quantity restrictions in the use of any sized buses.

3.5.1.2 Notations

To describe the model conveniently, Table 3.2 shows the notations that are used in the model.

Table 3.2: List of notations

Notations	Description
Indices	
i	Stop index, $1 \leq i \leq I$
k	Trip index, $1 \leq k \leq K$
l	Segment index, $1 \leq l \leq L$
Θ	Day index, $1 \leq \theta \leq \Theta$
Parameters	
τ_{il}	Travel time from stop i to stop $i+1$ on l-th time segment
T_s	Departure time for the first trip
T_e	Departure time for the last trip
H_{min}	Minimum headway among two adjacent trips
H_{max}	Maximum headway among two adjacent trips
δ	Length of a time segment
Fuzzy parameters	
$dwell_{ki}$	Dwell time from stop i to stop $i+1$ for the k-th trip
Decision variables	
K	Number of trips, $K \in [K_l, K_u]$ where K_l is lower bound and K_u is upper bound
t_{k1}	Departure time from stop 1 for the k-th trip, $2 \leq k \leq K-1$
Intermediate variables	
t_{ki}	Departure time from stop i of the k-th trip, $2 \leq i \leq I$, $1 \leq k \leq K$

3.5.1.3 Passenger load factor constraint

In this optimisation model, the passenger load factor is limited and does not exceed 1.0, to avoid operating overcrowded buses. Onboard crowdedness in a bus is a crucial factor on dwell time. Bus operators must follow the regulations prescribed by the government on the maximum passenger capacity of buses. Besides, the safety and comfort of passengers influence the bus service quality; the more passengers in a bus, the less service quality there is. Hence, passenger load factor is applied in this study.

For trip k, the number of passengers that remain onboard at station $i' \in I$ is

$$S_{ki'} = \sum_{i=1}^{i=i'-1} board_{ki} - \sum_{i=2}^{i=i'} alight_{ki} \tag{3.4}$$

The number of passengers boarding at station $i' \in I$ is

$$B_{ki'} = \begin{cases} board_{lki'}, if\, board_{ki'} \leq Max - S_{ki'} \\ Bus \max capacity_{bus\ type} - S_{ki'}, otherwise. \end{cases} \tag{3.5}$$

Therefore, the onboard passenger volume in a bus between station $i'$and stop $i' + 1$ for trip k is

$$p_{ki'} = S_{ki'} + B_{ki'} = \sum_{i=1}^{i=i'-1} board_{ki} - \sum_{i=2}^{i=i'} alight_{ki} + B_{ki'} \tag{3.6}$$

where,

$$\boldsymbol{l} = \left\lfloor \frac{t_{ki'}}{\delta} \right\rfloor + \mathbf{1}. \tag{3.7}$$

3.5.2 Objectives Function of Optimization Model

The bus service quality and efficiency are influenced by trip times (Bertini & El-Geneidy, 2004). Bus operators generally attempt to minimise the total trip time, which will benefit the passengers and reduce the operating cost such as fuel and salary of bus drivers. Bus trip time is the combination of dwell times and travel times in a trip. Dwell time is the main focus in this study, since the travel time is consistent throughout the observation period.

At the same time, bus operators also attempt to minimise the number of bus trips assigned on the timetable. The total number of bus trips, K, is within the range of $[K_l, K_u]$; where K_l represents the minimum number of bus trips while ensuring the transport quality and K_u is the maximum possible number of trips based on the operator's resources. By decreasing the number of bus trips, the dwell time for all trips along the bus route will also decrease. This objective causes the simulation to reduce the frequency of trips in order to decrease the total dwell time.

By considering the satisfaction of bus passengers, the total waiting time for all passengers at all stops are minimised. This objective aims to increase the total number of trips, K, in order to decrease the total passenger waiting time. The waiting time for all passengers is calculated as the departure time difference between two adjacent trips at every bus station. The calculation of passenger waiting time is based on the assumption that the arrival of passengers at the bus stations are uniformly distributed (Li et al., 2018):

$$\boldsymbol{Travel\,Time} = \boldsymbol{f(DT, MT, D)} \qquad \mathbf{3.8}$$

$$\Delta_{ki} = t_{ki} - t_{k-1,i} \qquad \mathbf{3.9}$$

subject to,

$$\boldsymbol{1 \le i \le I} \qquad \mathbf{3.10}$$

$$2 \le k \le K \qquad \mathbf{3.11}$$

The simulation of the bus timetable optimisation model by Li et al. (2018) is used in this study. Few changes are applied to fit the constraints of this study.

From the perspective of a bus operator, a bus timetable simulation should be set up as an objective to reduce the number of bus trips. However, this objective contradicts with the perspective of passengers which is to minimise their waiting time by increasing the number of bus trips. To balance the conflicting requirement between the two objectives of the bus operator and passengers, a bi-objective bus timetable optimisation is used to simulate an optimal bus timetable.

Minimize

$$T_d = \sum_{k=1}^{K} \sum_{i=1}^{I} dwell_{ki} \qquad \textbf{3.12}$$

$$T_w = \sum_{i=1}^{I} \left(\max_{2 \le k \le K} \Delta_{ki} \right) \qquad \textbf{3.13}$$

subject to:

$$\boldsymbol{H_{min} \le t_{k,1} - t_{k-1,1} \le H_{max}} \text{, where } \boldsymbol{2 \le k \le K} \qquad \textbf{3.14}$$

$$\boldsymbol{t_{ki} = t_{k,i-1} + d_{ki}}, \text{ where } 1 \le \boldsymbol{k \le K} \qquad \textbf{3.15}$$

$$\boldsymbol{t_{1,1} = T_s} \qquad \textbf{3.16}$$

$$\boldsymbol{t_{K,1} = T_e} \qquad \textbf{3.17}$$

$$\boldsymbol{2 \le i \le I} \qquad \textbf{3.18}$$

$$\boldsymbol{2 \le l \le L} \qquad \textbf{3.19}$$

The first objective (3.12) minimises the total dwell time of all trips along the bus route. The second objective (3.13) minimises the total passenger waiting time at all bus stations. The first constraint (3.14) defines the minimum and maximum headways between two adjacent trips. The second constraint (3.15) calculates the departure times from different bus stations. The third and fourth constraints (3.16 & 3.17) state the departure times for the first trip and last trip. The last two constraints (3.18 & 3.19) are the indices for the station and trip.

3.5.3 Calculation of Objective Value for Two Objective Functions

In order to address this bi-objective bus timetable optimisation problem, a weighted method is used to convert the bi-objective problem into a single objective problem. ${f_1}_{min}$ (minimum expected total dwell time), ${f_1}_{max}$ (maximum expected total dwell time), ${f_2}_{min}$ (minimum expected total passenger waiting time) and ${f_2}_{max}$ (maximum expected total passenger waiting time) are calculated. A random number, $\lambda \in [0, 1]$ is used as the relative importance degree on the two objectives. The objective function of a weighted bi-objective model is constructed as below:

$$\min \lambda \frac{f_1 - {f_1}_{min}}{{f_1}_{max} - {f_1}_{min}} + (1 - \lambda) \frac{f_2 - {f_2}_{min}}{{f_2}_{max} - {f_2}_{min}} \qquad \mathbf{3.20}$$

Since both objectives are equally important, $\lambda = 0.5$ is used in this study which represents both objectives having equal weightage.

3.5.4 Genetic Algorithm (GA)

The bus timetable optimisation model is an integer nonlinear programming due to the high complexity on this optimisation model (Li et al., 2018). The simulation optimisation approach by Li et al. (2018) is modified and used to approximate the total dwell time and total passenger waiting time.

Genetic algorithm (GA) is one of the metaheuristic methods to solve high complexity optimisation problem (Davis, 1991; Holland, 1975). GA is used on Microsoft Visual C++

2010 to solve the bus optimisation model by generating an optimal bus timetable. A GA with variable-length chromosomes is designed and used to solve the bi-objective bus timetable optimisation model.

3.5.4.1 Representation structure

A chromosome v consists of two rows; the first row consists the bus type used of each trip, whereas the second row consists of the departure time of each bus trip. K is the total bus trips, $x_1 = T_s$ and $x_K = T_e$ denote the departure time of the first and last bus trip respectively. There are two types of buses, in which 0 represents the two-door bus is used and 1 represents the one-door bus is used.

3.5.4.2 Initialization

An integer pop_size is defined as the size of population and a real number K from $[K_l, K_u]$ is generated randomly. Then a chromosome $v = (t_{1,1}, t_{2,1}, \dots, t_{K,1})$, where $t_{1,1} = T_s$ and $t_{K,1} = T_e$. Random number u_i is generated randomly, where $i = \{1,2,\dots,K-1\}$, within the range of $[H_{min}, H_{max}]$, satisfying the condition:

$$\sum_{i=1}^{K-1} u_i = T_e - T_s \qquad \textbf{3.21}$$

A feasible chromosome is generated by $t_{i+1,1} = t_{i,1} + u_i$, $i = \{1,2,\dots,K-2\}$. Above steps are repeated for pop_size times and denote the generated chromosomes as $\boldsymbol{v}_i, i = 1,2,\dots,pop\_size$.

3.5.4.3 Evaluation function

The evaluation function is used to assign a reproduction probability for each chromosome. The likelihood of a chromosome being selected is proportional to its relative fitness. The evaluation function is defined as follows:

$$Eval(\boldsymbol{v}_i) = \alpha(1-\alpha)^{i-1} \quad \textbf{3.22}$$

where $\alpha \in (0,1)$ and $i = 1,2,\dots,pop\_size$. The chromosomes are arrange based on the evaluation value where $\boldsymbol{v}_1$ being the best chromosome and $\boldsymbol{v}_{pop\_size}$ being the worst.

3.5.4.4 Selection operation

The method of roulette wheel spinning is used to select chromosomes which breed a new generation. The chromosomes with larger fitness are more likely to be selected and the selection process is summarized in Algorithm 1 (Li et al., 2018). First, the reproduction probability, q_i is generated for each chromosome $\boldsymbol{v}_i$, $i = 1,2,\dots,pop\_size$ as follows:

$$q_0 = 0, q_i = \sum_{j=1}^{i} Eval(\boldsymbol{v}_j) \quad \textbf{3.23}$$

Next, a random number r in $(0, q_{pop\_size}]$ is generated and chromosome is selected if $q_{i-1} < r \leq q_i$. The previous step is repeated pop_size times and pop_size chromosome is obtained.

3.5.4.5 Self-crossover operation

Self-crossover is one of the operations used for generating population for following generation. Crossover probability, P_c is defined. A random number $r_i \in [0.1]$ is generated. A chromosome $\boldsymbol{v}_i$ is selected as parent if $r_i \leq P_c$. First, two disjoint segments with length of one hour are selected randomly from $[T_s, T_e]$. Next, for the selected chromosome, judge the corresponding sections in the two segments based on the second rows (bus depart time). Thirdly, the two selected disjoint sections of chromosome are exchanged and the bus trip departure times. A child chromosome will be obtained. Repeat the above steps $\frac{1}{2} * pop\_size$ times. The self-crossover can make the child chromosome satisfy the number of bus trips and the structure of chromosome is not damaged (Yu et al., 2017).

3.5.4.6 Mutation operation

For each chromosome, the probability of mutation, P_m is defined. A random number $r_i \in [0.1]$ is generated. A chromosome $\boldsymbol{v}_i$ is selected as parent for mutation operation if $r_i \leq P_m$. Firstly, randomly select n time periods (1-hour length each) from the operation time $[T_s, T_e]$. Next, regenerate the selected time period sections. The chromosome row for type of bus used are randomly regenerated a series of numbers from set $\{1,2\}$. The chromosome row for bus trip departure time are regenerated with the subject to trip number and maximum and minimum headway constraints. A new chromosome which contained bus type used and bus trip departure time will be obtained.

3.5.4.7 Overall summary

A new population for next generation is generated after the selection, crossover, and mutation operations. GA will terminate after a given number of maximum iterations of the above steps. The general procedure for the GA-based solution method is summarised as below (Li et al., 2018):

Algorithm 2: *Genetic Algorithm by Li et al. (2018)*

Step 1 Randomly initialize pop_size chromosomes, $iteration = 0$.

Step 2 Calculate objective values for all chromosomes.

Step 3 Evaluate fitness of each chromosome using objective values.

Step 4 Select chromosomes by spinning roulette wheel.

Step 5 Update chromosomes using self-crossover and mutation.

$if\ (iteration < maximum\ iterations)$
$\quad i + 1, goto\ Step\ 2$
$else$
$\quad report\ best\ found\ chromosome\ as\ optimal\ solution$

CHAPTER 4: RESULTS AND DISCUSSIONS

This chapter presents the results of all the data analysis. It is divided into four sections followed by a summary. The first section will cover results of the questionnaire survey on the satisfactory level of the campus bus service based on the passenger riding experience. The second section will discuss the analysis on passenger demand and person capacity with passenger load factor (PLF), which contains the analysis of the level of crowdedness on the bus at different stations as well as at different time periods. The third section of this chapter is a discussion on the dwell time model analysis and present the factors that affect a bus's dwell time. This section also provides the analysis result on the relationship between dwell time and different passenger load level on the operating bus. Finally, an optimal bus timetable is proposed and presented in the last section of this chapter. A comparative analysis between the current bus timetable and proposed bus timetable will also be done.

The bus data were collected for different bus routes from 8:00a.m. to 7:00p.m. in a day. The focus was on the peak periods which are the morning peak from 8:00a.m. to 10:00a.m., the noon peak from 12:00p.m. to 2:00p.m. and the evening peak from 4:00p.m. to 7:00p.m. Bus Route A serves 10 stops consisting five residential colleges, whereas Bus Route B serves seven stops consisting four residential colleges. Both bus routes depart from the Academic of Islamic Studies (API) station, using different path towards UM Central (UMC) station and back to API. Both bus routes connect the areas between different residential college areas and the centre of the university. The route length for Bus Route A and Bus Route B are 6.3 km and 5.5 km respectively. The operating hours for both bus routes are from 7:20 a.m. to 11:30 p.m.

4.1 Satisfaction Level of Bus Passengers

A questionnaire survey was done to collect feedback on the satisfaction level on the transit bus performance. Furthermore, a rating and recommendation for each on-campus bus route and overall campus bus service were also asked in the questionnaire. The questionnaire survey was carried out from 7th March 2017 to 21st March 2017 with a total of 419 respondents. The questionnaire was done using the Google Forms platform. Table 4.1 shows the student population of University of Malaya (UM) in different categories.

Table 4.1: Student population of UM (Source: https://www.um.edu.my/about-um/um-fact-sheet (2016))

Category		Number
Local Student	Undergraduate	7599
	Postgraduate	6269
International Student	Undergraduate	701
	Postgraduate	3011
Total Number of Student		17580

4.1.1 Demographic Data

The demographic data shows the socio-economic statistics of the UM student population. Figure 4.1 to Figure 4.6 show the distribution of demographic information of the respondents, such as gender, nationality, age distribution, student status in UM, faculty, and residential area.

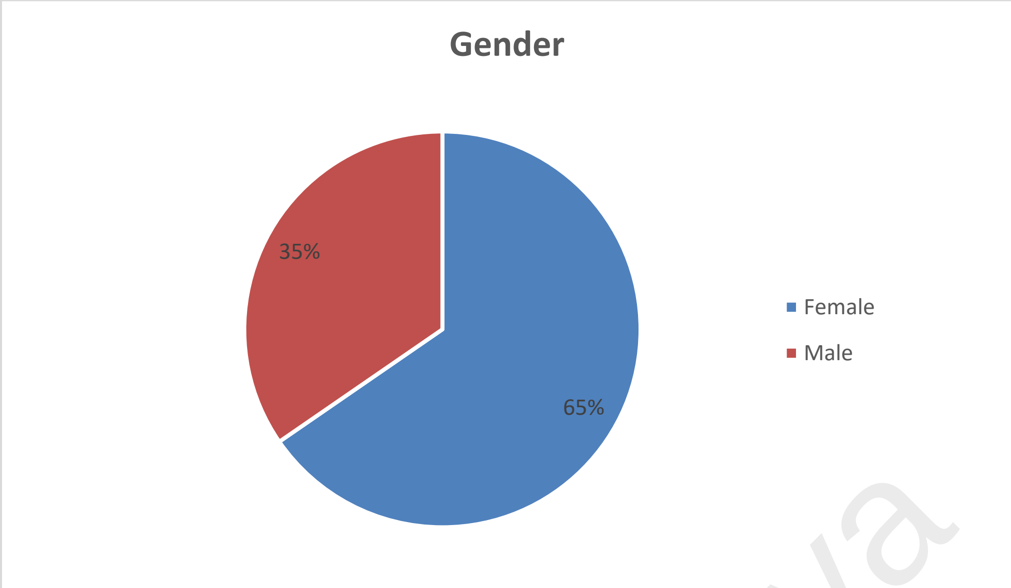

Figure 4.1: Gender distribution

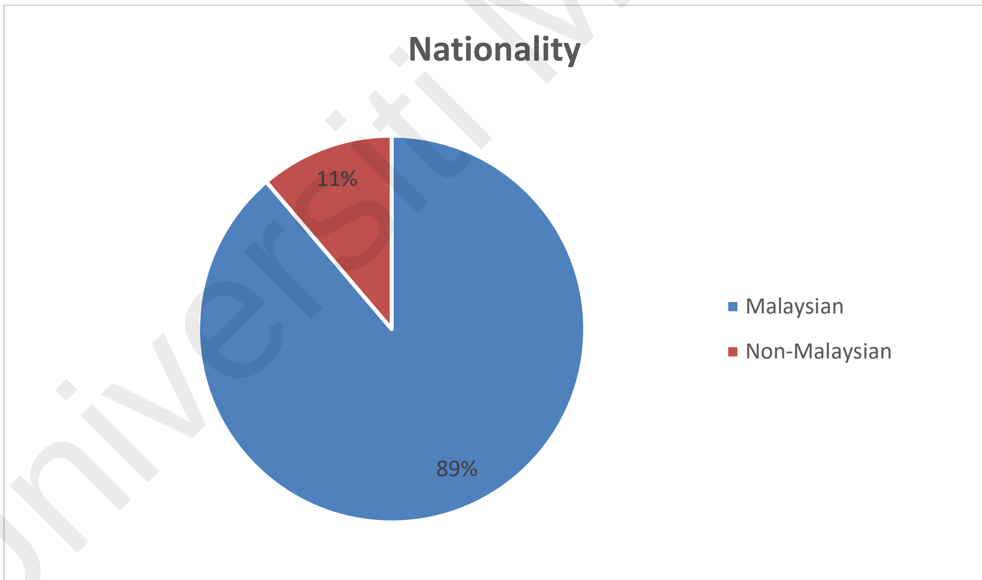

Figure 4.2: Nationality distribution

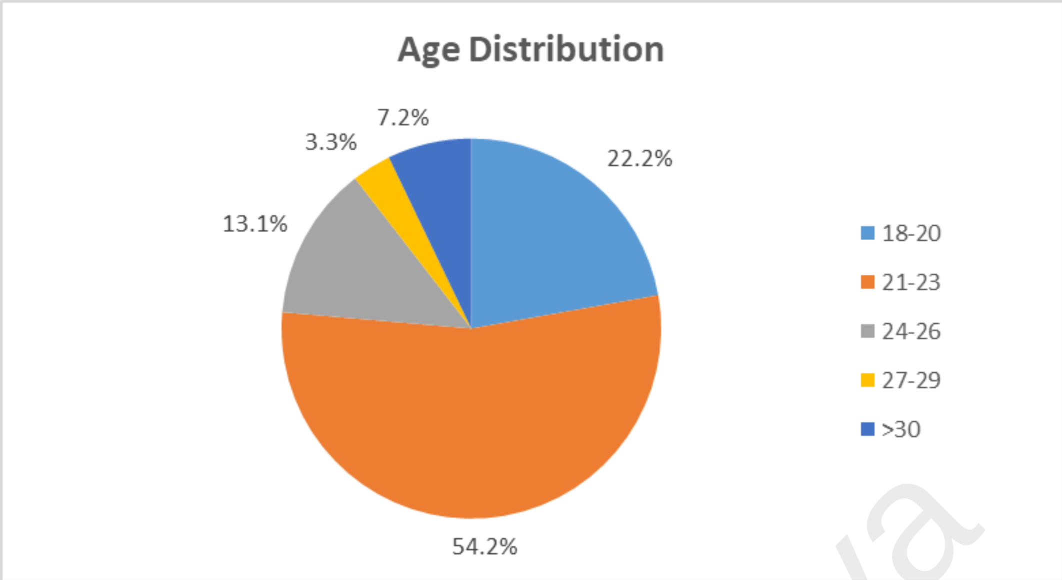

Figure 4.3: Age distribution

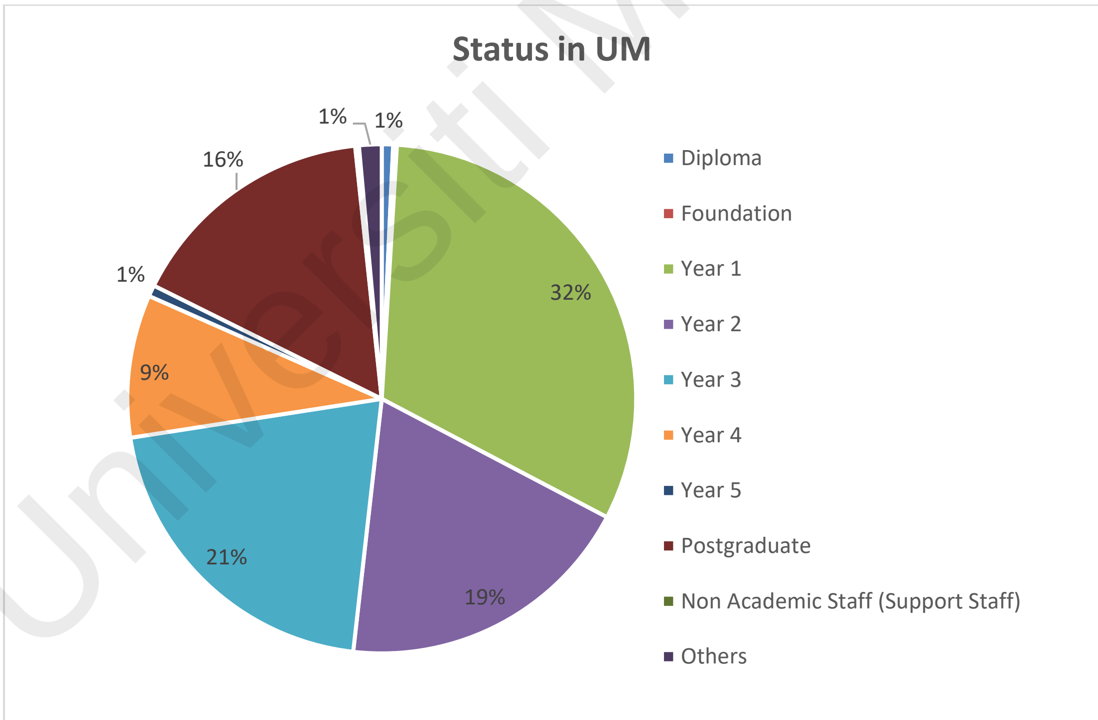

Figure 4.4: Status of students in UM

Overall, 65% of the respondents are female and 35%, male. Among the 419 respondents, there are 89% who are Malaysian students and 11% are foreign students. In terms of age distribution, the majority of respondents are between 21 and 23 years old, which consists 54.2% of respondents; the second highest age group is between 18 and 20 years old, making up 22.2% of the respondents. Furthermore, 82% of the respondents are undergraduate students, 16% are postgraduate students and the rest are of the foundation and diploma studies category.

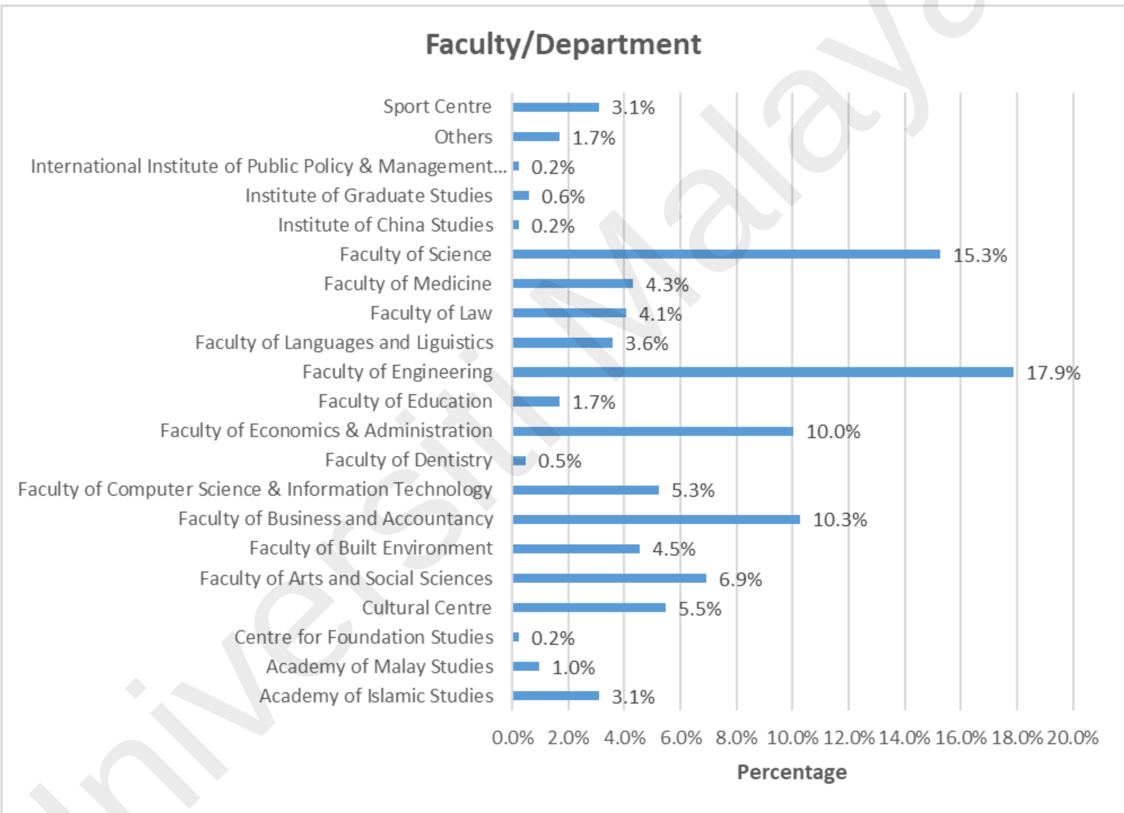

Figure 4.5: Faculty/Department distribution

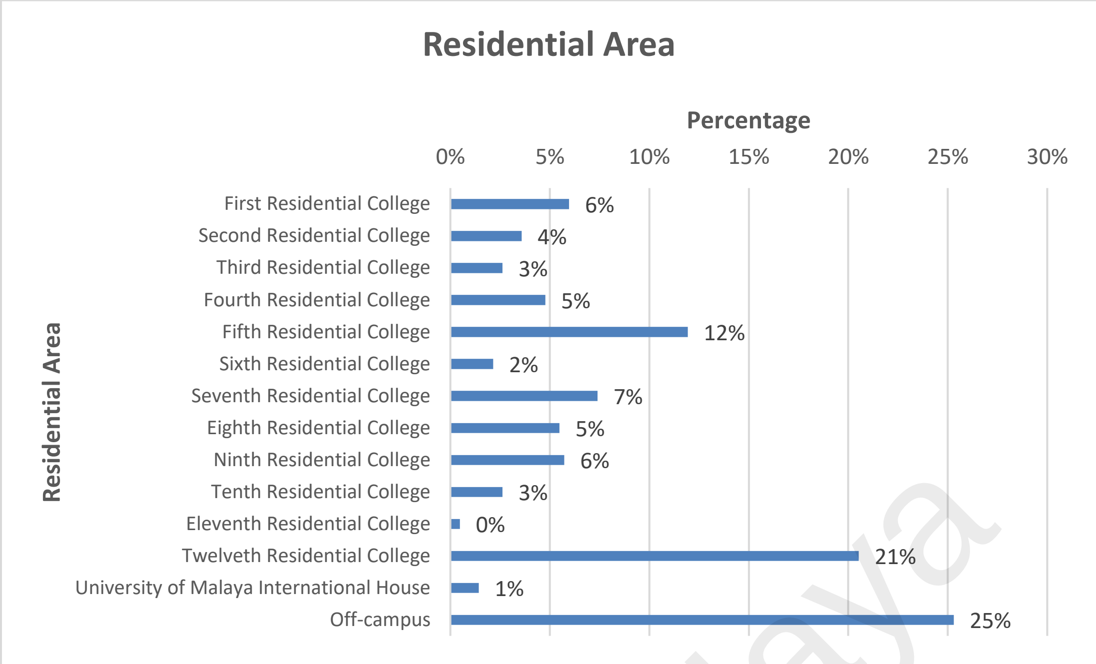

Figure 4.6: Residential area distribution

More than 10% of the total respondents are from the Faculty of Business and Accountancy, Faculty of Economics and Administration, Faculty of Engineering and Faculty of Science respectively. Regarding the residential area of students, 68% of respondents live on campus, 6% live at the Ninth Residential College and 26% of respondents stay off campus, including at the UM International House. Among the respondents who stay on campus, 23% and 43% of respondents stay at residential colleges along Bus Route A and Bus Route B respectively.

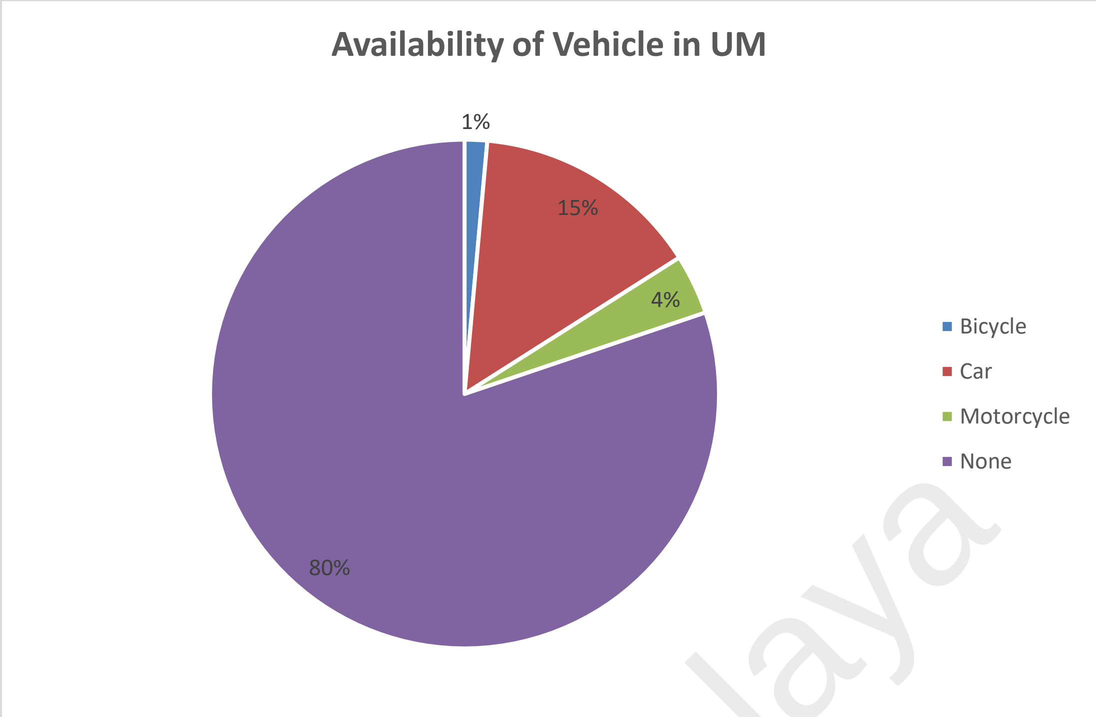

Figure 4.7: Availability of vehicle in UM

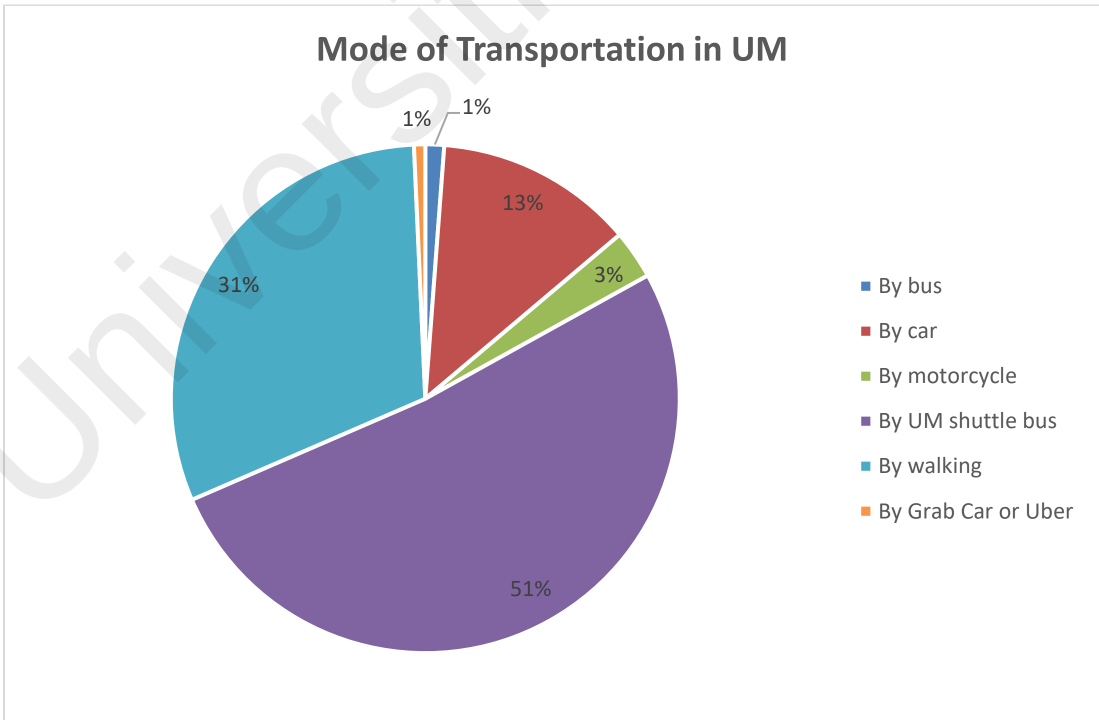

Figure 4.8: Mode of transportation in UM

Figure 4.7 and Figure 4.8 show the vehicle availability of students and the transportation modal split of respondents respectively. There are 80% of respondents who do not own any vehicle in UM while the rest of them own either a car, motorcycle or bicycle. Among those with a form of vehicle ownership, car owners make up the largest group, occupying 15% of the overall respondents. This result correlates with Figure 4.8 where the modal split of respondents travelling by bus and walking occupy about 82% of the total respondents, and about 13% of the them travel by car.

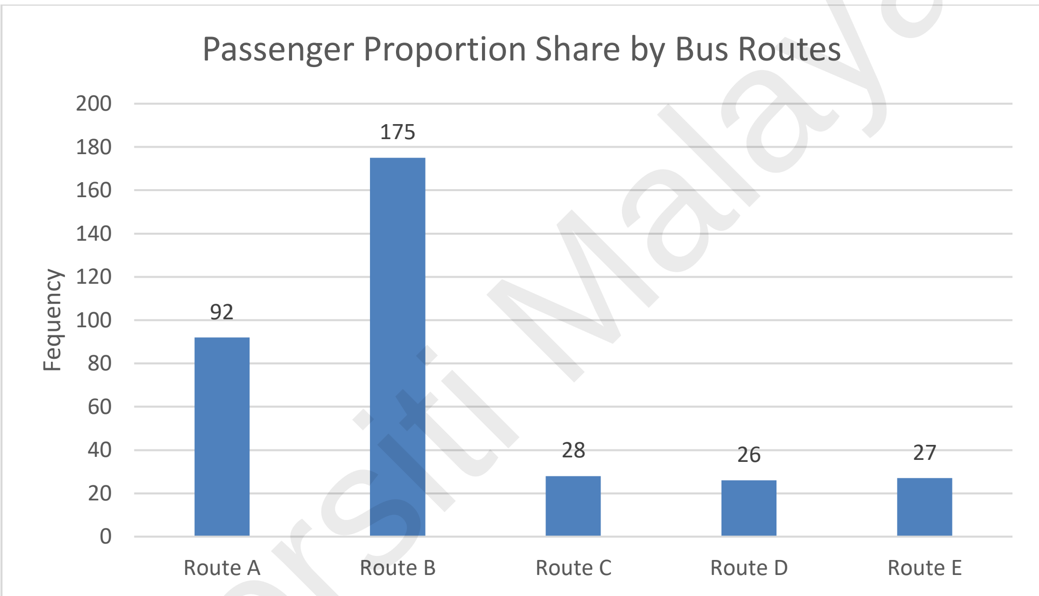

Figure 4.9: Bus routes that travelled the most in UM

Figure 4.9 shows the share of different UM bus routes for those who use the bus as their main transportation mode. Out of the total number of respondents, 348 (83%) of respondents have used the campus bus since Semester One of Session 2016/2017. The proportion of bus routes that are travelled the most by those 350 respondents are depicted in Figure 4.9. Bus Route B has a higher share of passenger proportion than Bus Route A.

4.1.2 Transit Service Analysis on Different Bus Routes

The transit bus service performance of both routes are analysed separately. The bus service satisfaction level, opinion on specific issues of the bus service and recommendations on the current bus service are discussed in this section. An overall transit service analysis on areas such as the frequency of bus service usage within a week, the traffic congestion factor on campus, feedback and opinion on transportation issues and the rating on quality of the overall service are generally discussed at the end of this section.

4.1.2.1 Bus Route A

The questionnaire survey results specifically for Bus Route A are summarised in Figure 4.10, Figure 4.11, and Figure 4.12 which consist of satisfactory level on the bus performance, issues and recommendations on the current bus service.

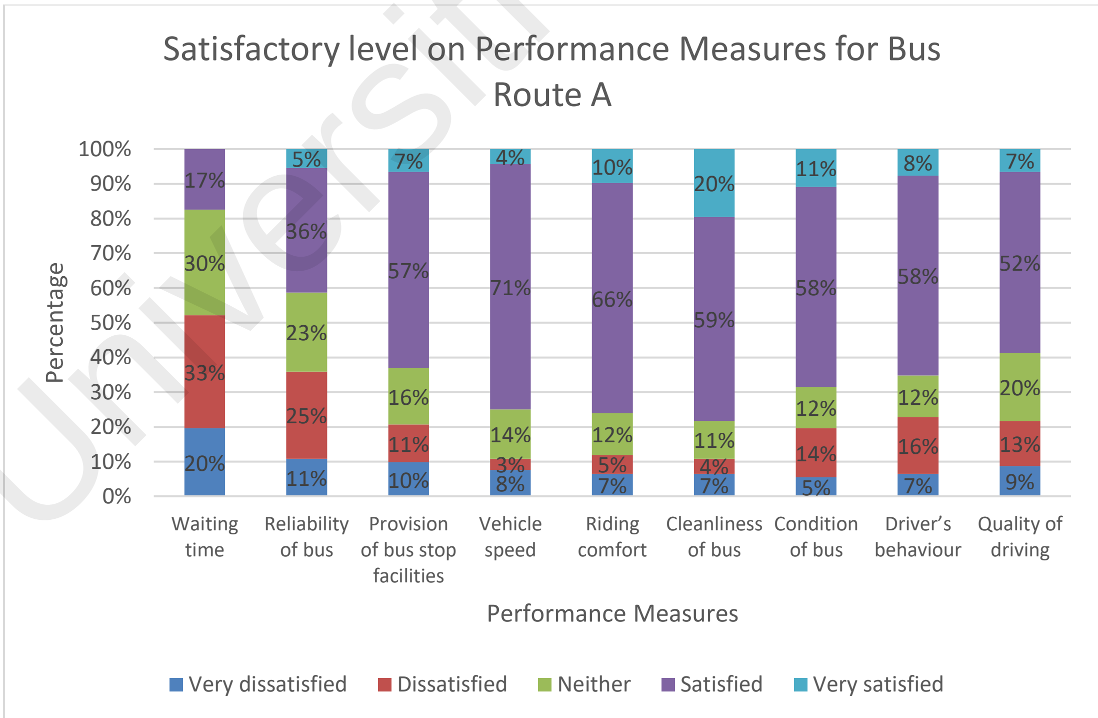

Figure 4.10: Satisfactory level on performance measure for Bus Route A

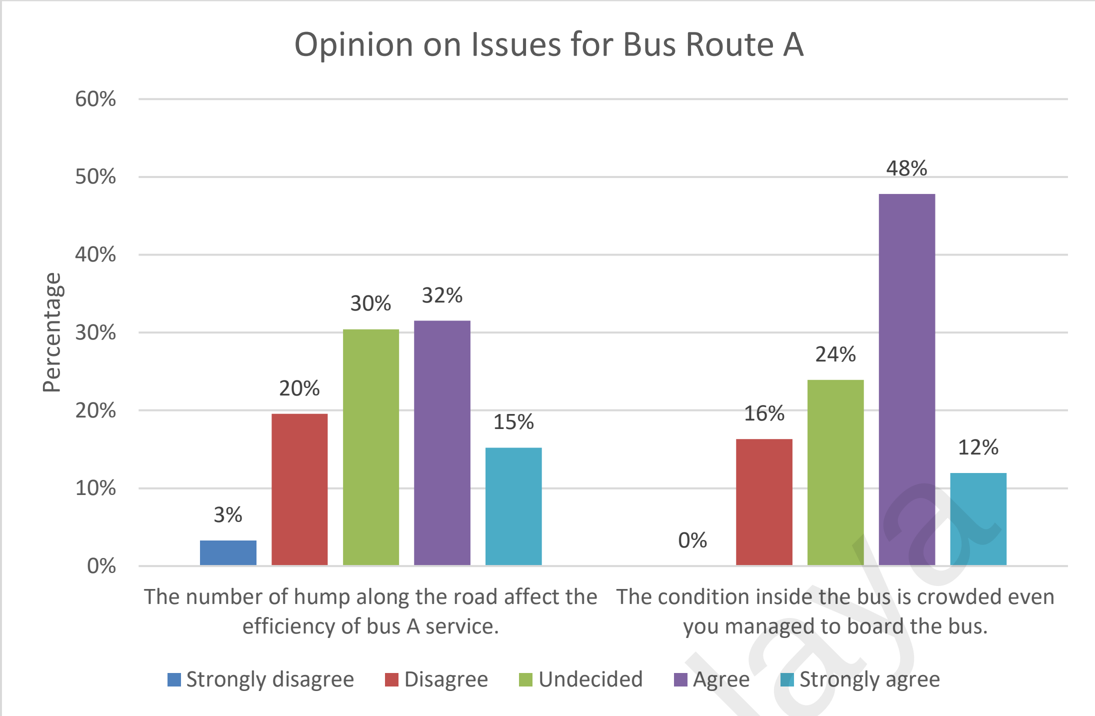

Figure 4.11: Opinion on issues for Bus Route A

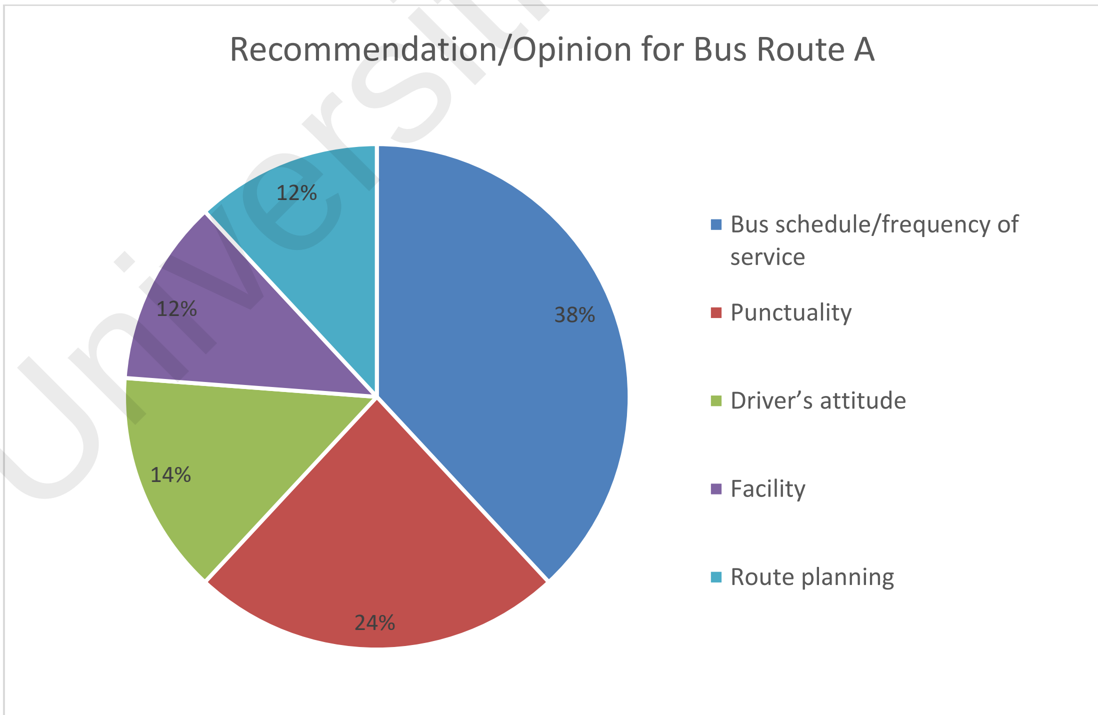

Figure 4.12: Recommendation/opinion for Bus Route A

Figure 4.10 shows that most of the respondents for Bus Route A are satisfied with the cleanliness of bus, riding comfort, and vehicle speed. However, majority of the respondents are dissatisfied with the waiting time for bus arrivals at the stations. From Figure 4.11, a total 32% of respondents agree that the hump affects the efficiency of the bus trip while 30% of them has no opinion on this issue. Furthermore, 48% of the respondents agree with the existence of on-board crowding issue and 12% of them feel strongly agree about this condition, meaning that 60% of respondents think that the bus is crowded. Figure 4.12 shows the recommendation and opinion from respondents on the bus schedule, which mainly suggest to increase trip frequency during peak hour. Besides, the punctuality of the driver should be improved.

4.1.2.2 Bus Route B

The results of the questionnaire survey for Bus Route B are summarised in Figure 4.13, Figure 4.14, Figure 4.15, and Figure 4.16 which include the satisfaction level of the bus performance, crowdedness issue and recommendation for the current bus service.

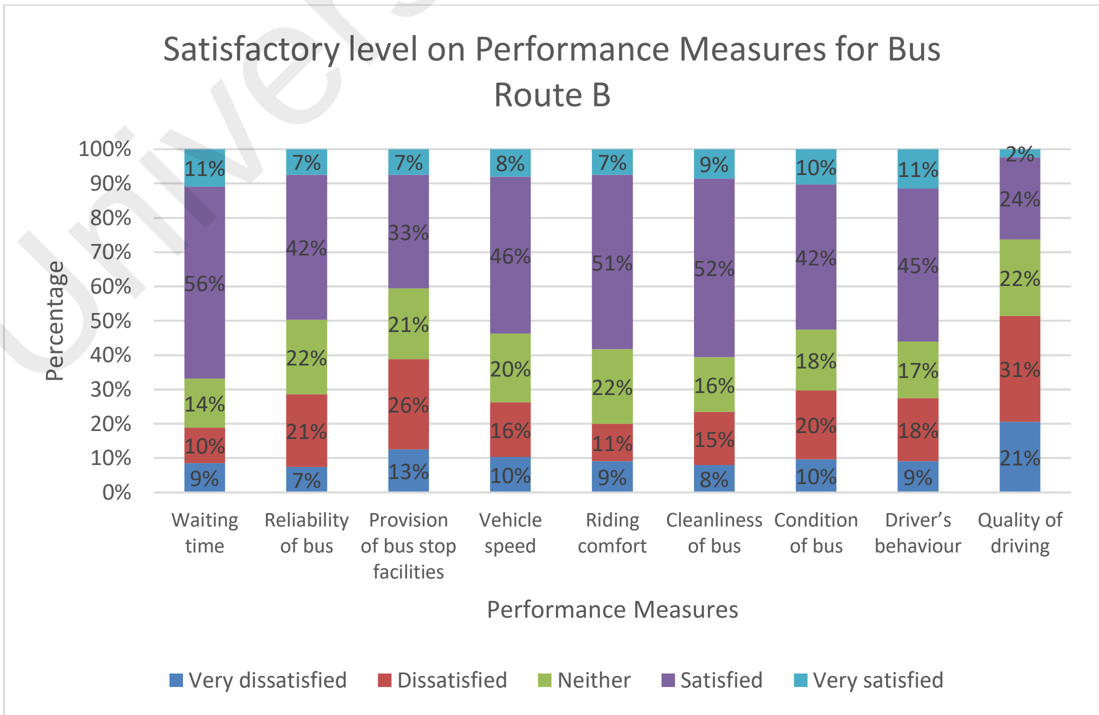

Figure 4.13: Satisfactory level on performance measure for Bus Route B

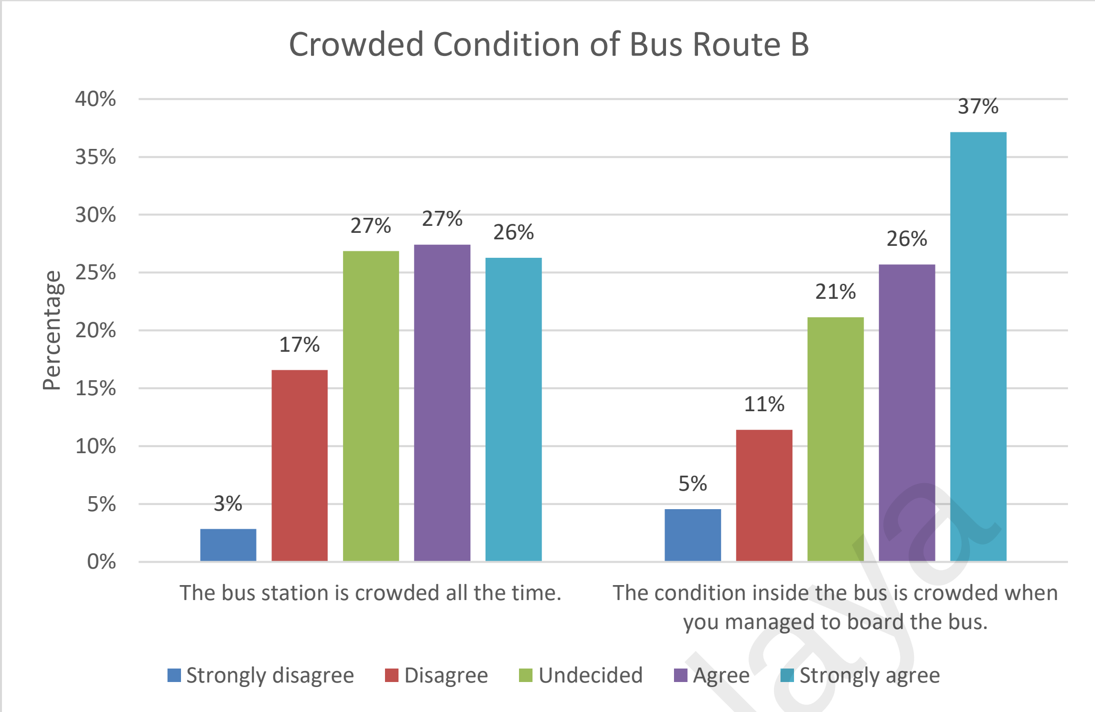

Figure 4.14: Crowded condition of issues for Bus Route B

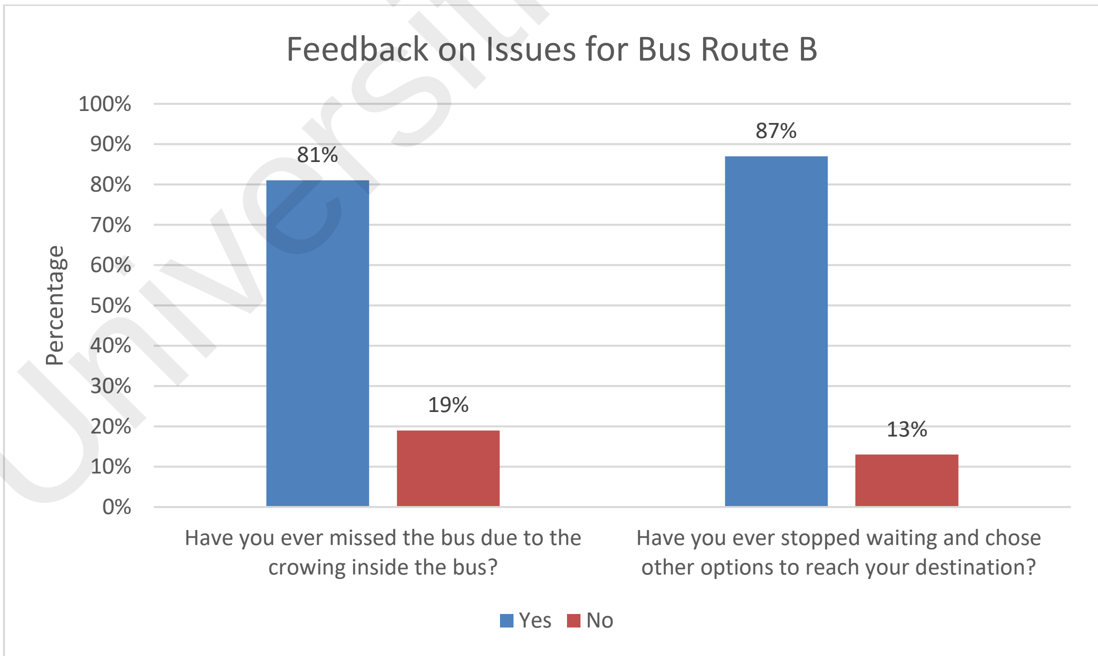

Figure 4.15: Feedback on issues for Bus Route B

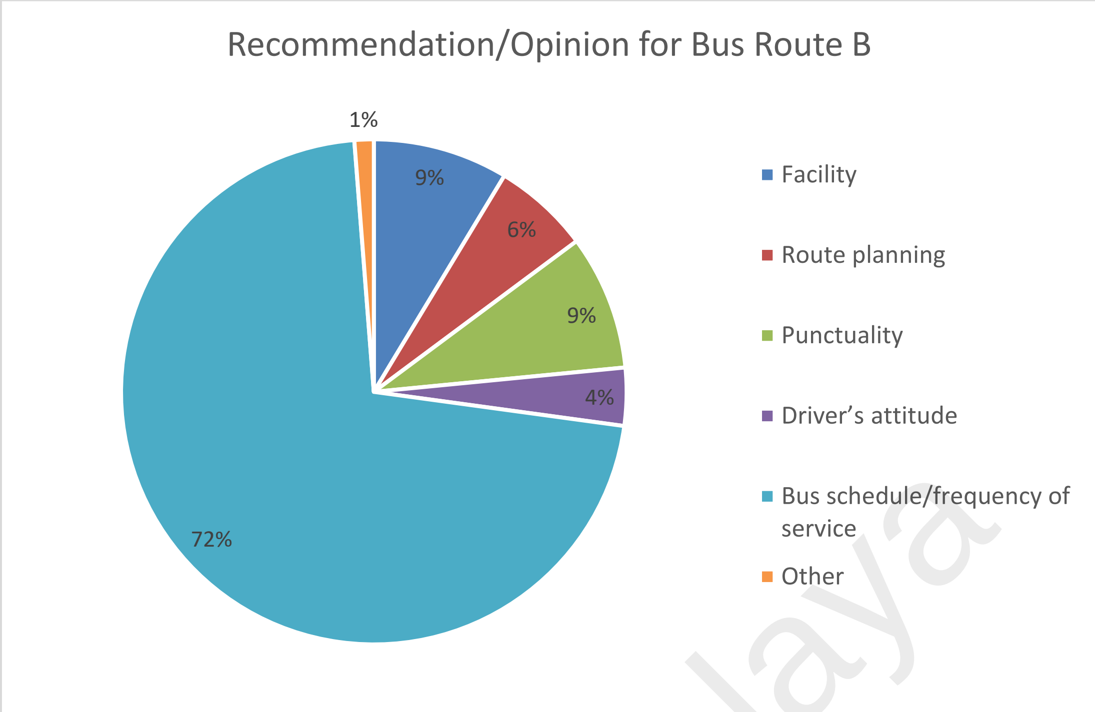

Figure 4.16: Recommendation/opinion for Bus Route B

Unlike Bus Route A, most of the passengers from Bus Route B are satisfied with most of the services including the average waiting time. Only the quality of driving was rated with dissatisfaction. Figure 4.14 shows that the on-board crowdedness is more serious than that at the bus station, which the majority proportion of respondents have strongly agreed with. More than 80% of the respondents chose to stop waiting for the bus and opted for an alternative transportation mode due to the long waiting time for the arrival of the bus. Besides, 81% of the respondents have had experiences where they were unable to board a bus due to an overloading of passengers in the bus. Figure 4.16 shows that more than 70% of the respondents were dissatisfied with the current bus schedule and trip frequency. Some respondents also suggested additional bus trips or using buses with higher capacity during peak hours to solve the issue of overloaded buses.

4.1.2.3 Overall transit performance

The analysis on the overall transit performance includes factors such as congestion on campus, feedback on transportation issues and overall service quality of the campus bus service. The comments from respondents are summarised in Figure 4.17, Figure 4.18, Figure 4.19, and Figure 4.20.

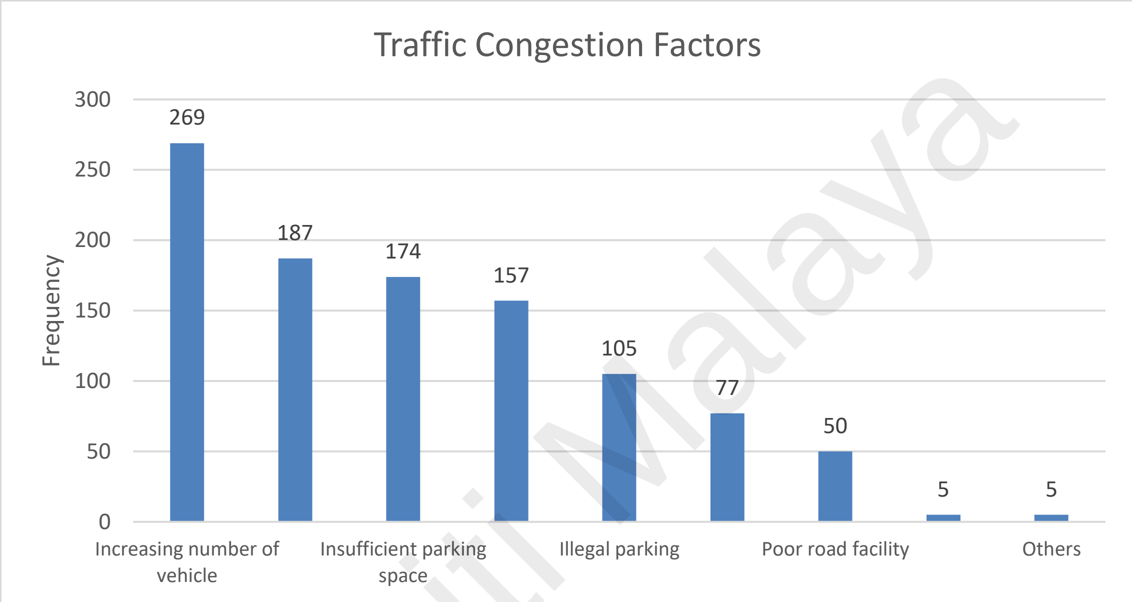

Figure 4.17: Factors contributing to congestion within UM Campus in frequency

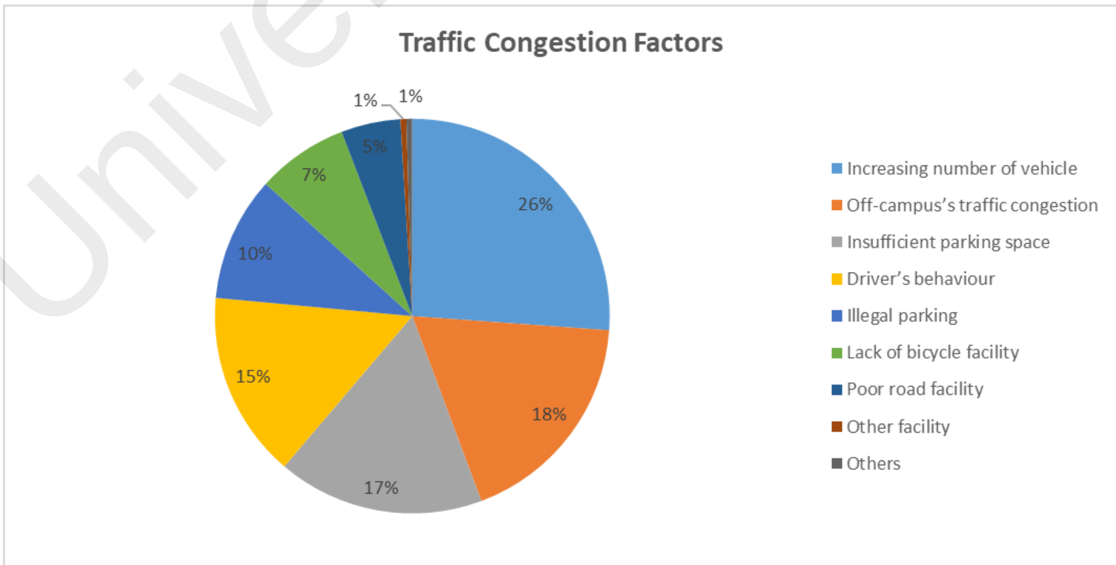

Figure 4.18: Factors contributing to congestion within UM Campus in percentage

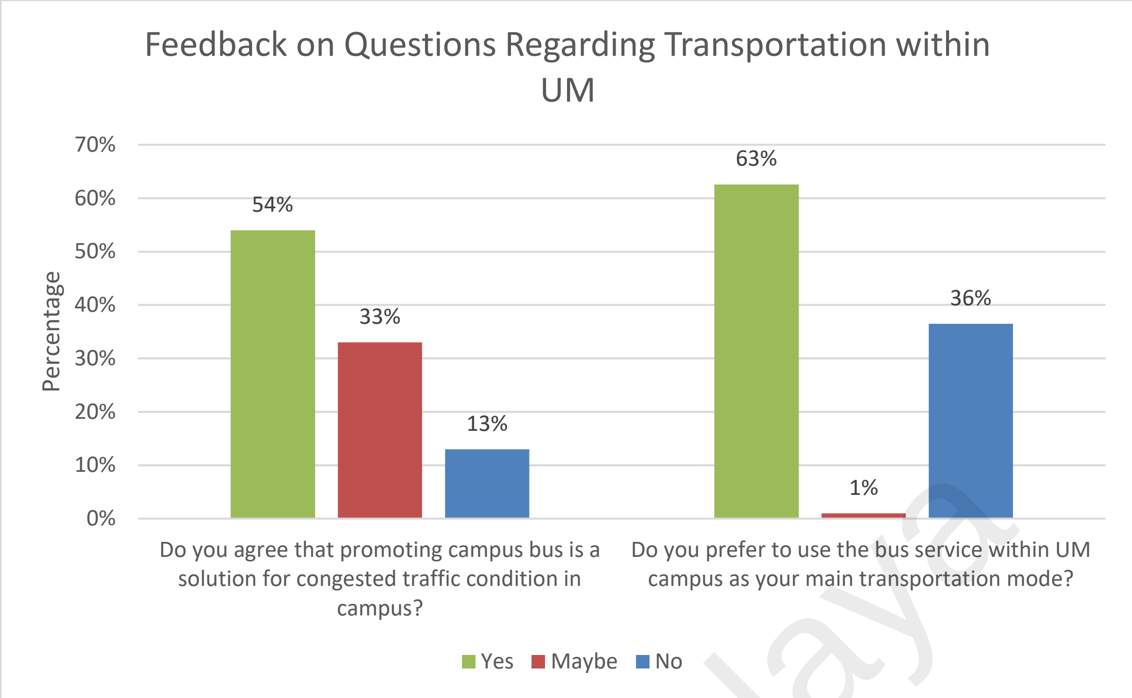

Figure 4.19: Feedback on question regarding transportation within UM Campus

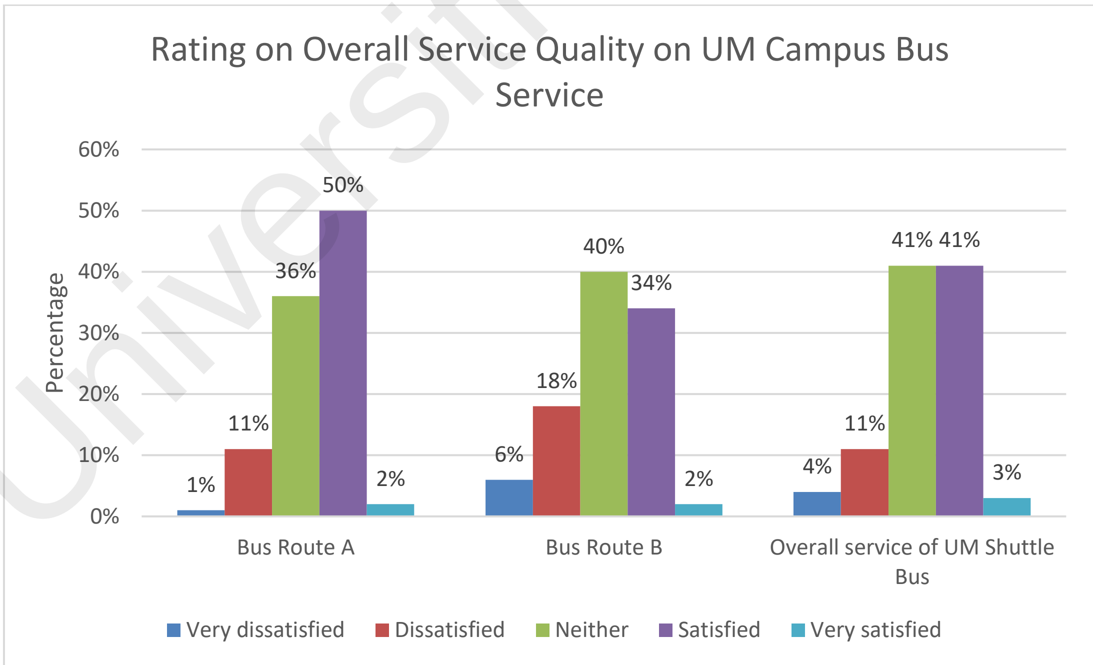

Figure 4.20: Rating of overall transit performance on UM campus bus service

In respect to the factors of congestion on UM campus, increasing number of vehicles, off-campus's traffic congestion, insufficient parking space, driver's behaviour and illegal parking were total garnered more than 75% of respondents. These factors are often interrelated, which subsequently causes the deterioration of the transit bus performance. It was suggested that the increasing number of vehicles on campus was the main contributor to the congestion issue. Majority of the respondents agree that promoting the UM campus bus service is one of the solutions to ease traffic congestion on campus.

Most of the respondents are neutral on the improvement of the bus service quality, they were neither satisfied nor dissatisfied. However, most of them preferred to use the campus bus service as their main transportation mode on UM campus. Besides, Figure 4.20 shows that the rating of the overall transit performance of all on-campus bus routes was satisfactory.

4.1.3 Interaction Analysis on Bus Service Issue

4.1.3.1 Influence of vehicle availability on preference of transportation mode

Figure 4.21 shows that majority of the respondents without transportation had used the UM bus service before.

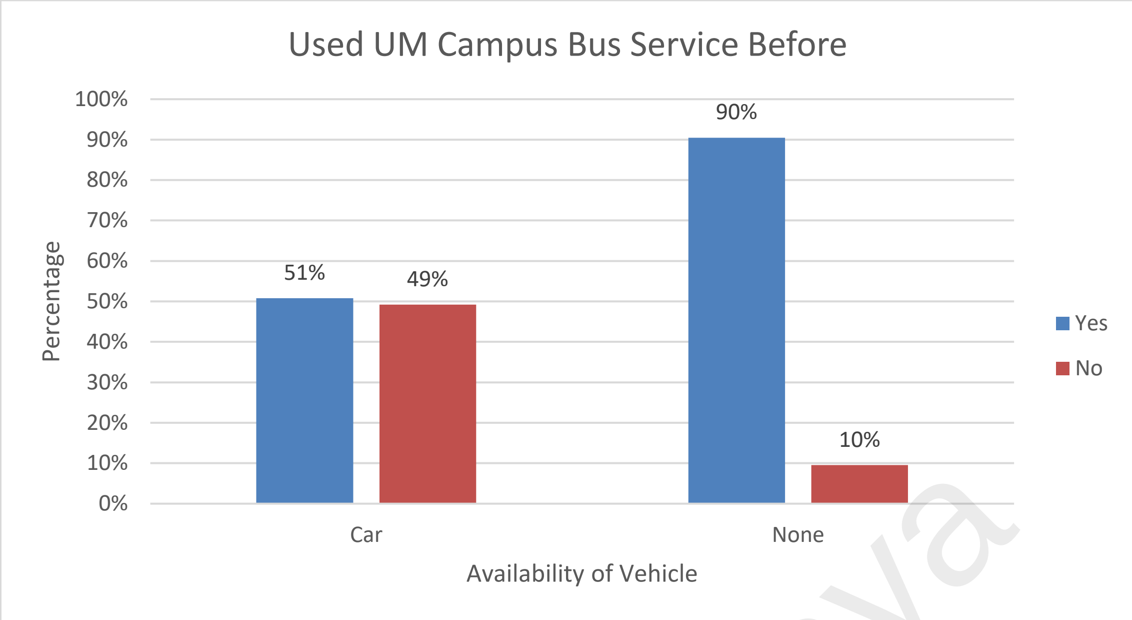

Figure 4.21: Availability of vehicle vs. used campus bus service before

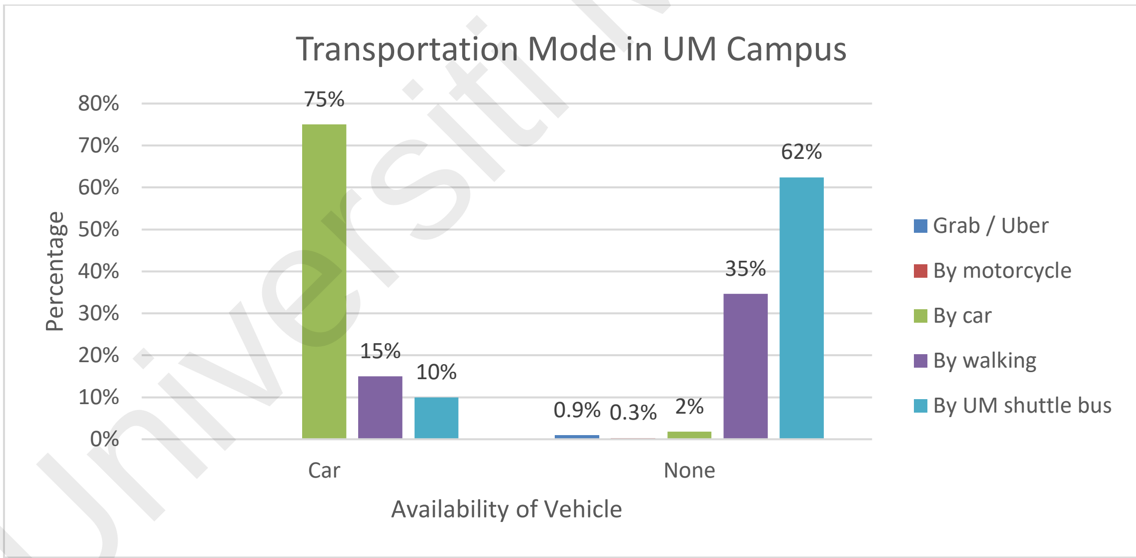

Figure 4.22: Availability of vehicle vs. mode of transportation in UM campus

Figure 4.21 shows that most of the respondents without their own transportation are using the campus bus service to travel in campus. Interestingly, Figure 4.22 also shows that only 10% of car owners among the respondents are using the campus bus as the main transportation mode in campus and half of the car owners among the respondents have also used the UM campus bus before. Furthermore, more than 70% of the car owners use cars as transportation mode in campus.

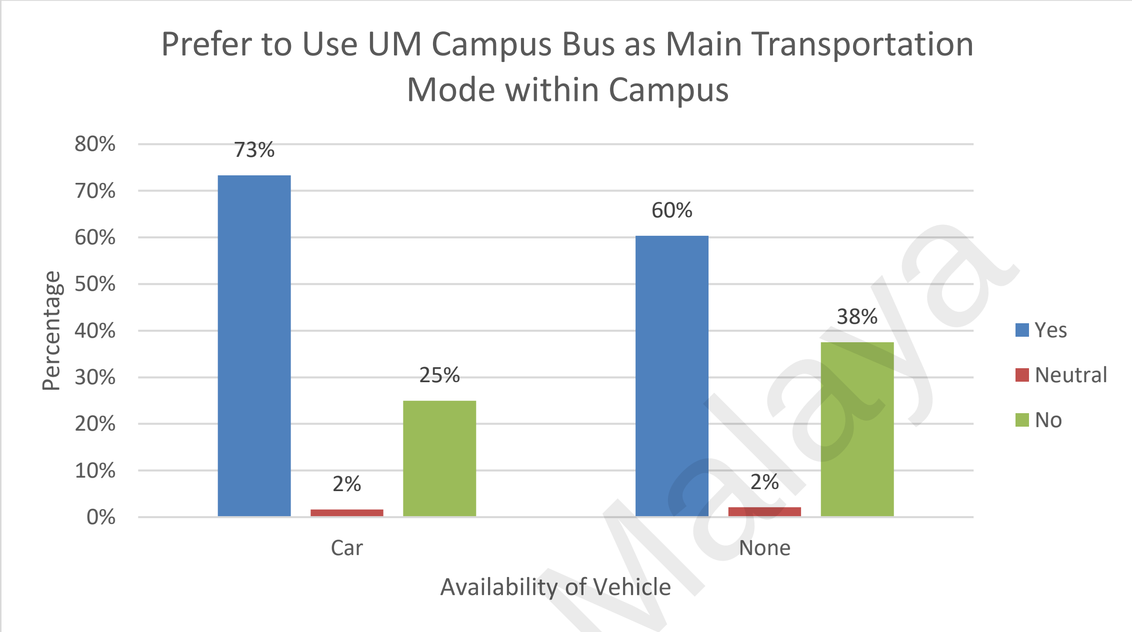

Figure 4.23: Preference to use UM campus bus as main transportation mode

Figure 4.23 shows that more than 70% of the car owners would prefer to use the campus bus service as the main transportation mode within the campus. This will be an effective transportation modal shift for car owners from their private vehicle to the campus bus service provided a high quality of campus bus service is available.

4.1.3.2 Waiting duration of bus arrival on different bus routes

Figure 4.24 shows the average waiting duration of bus arrivals on different bus routes. Among the respondents from Bus Route A, most of the waiting time for bus arrivals are between six and 15 minutes.

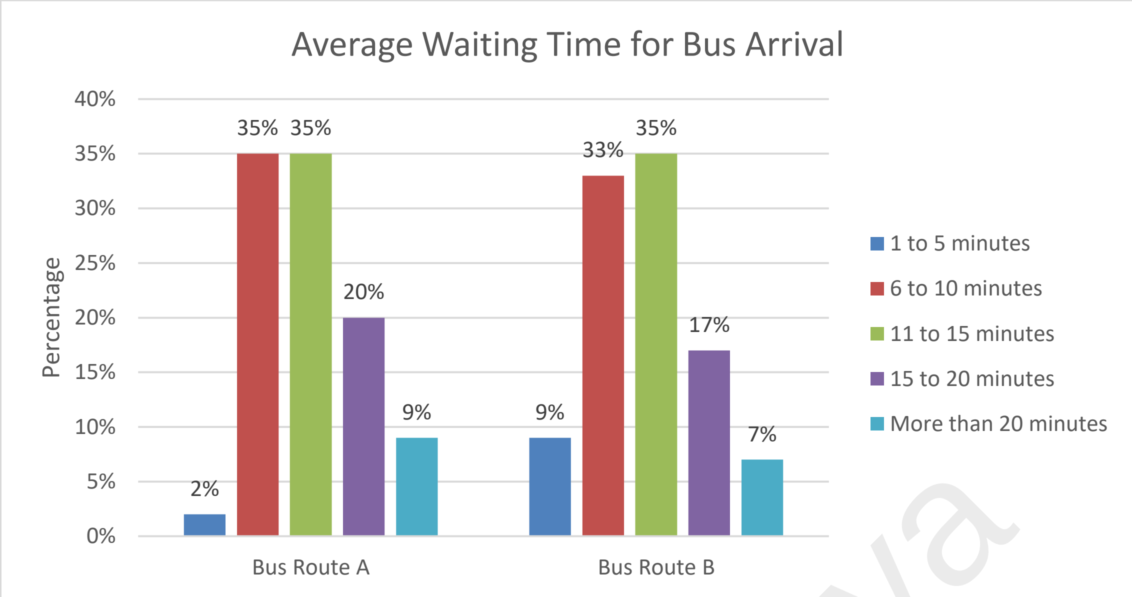

Figure 4.24: Average passenger waiting time for bus arrival

For Bus Route B, the average waiting time for a bus arrival with the highest percentage is between 11 and 15 minutes, as supported by 35% of the respondents. The second highest bus arrival waiting time for Bus Route B is between six and 10 minutes, which consists 33% of the respondents, which is very close to the highest waiting time group. The average bus arrival waiting time for Bus Route A and Bus Route B show a similar range. Figure 4.25 shows the satisfaction level on the waiting time of a bus arrival. The results of Figure 4.25 are also classified according to different bus routes.

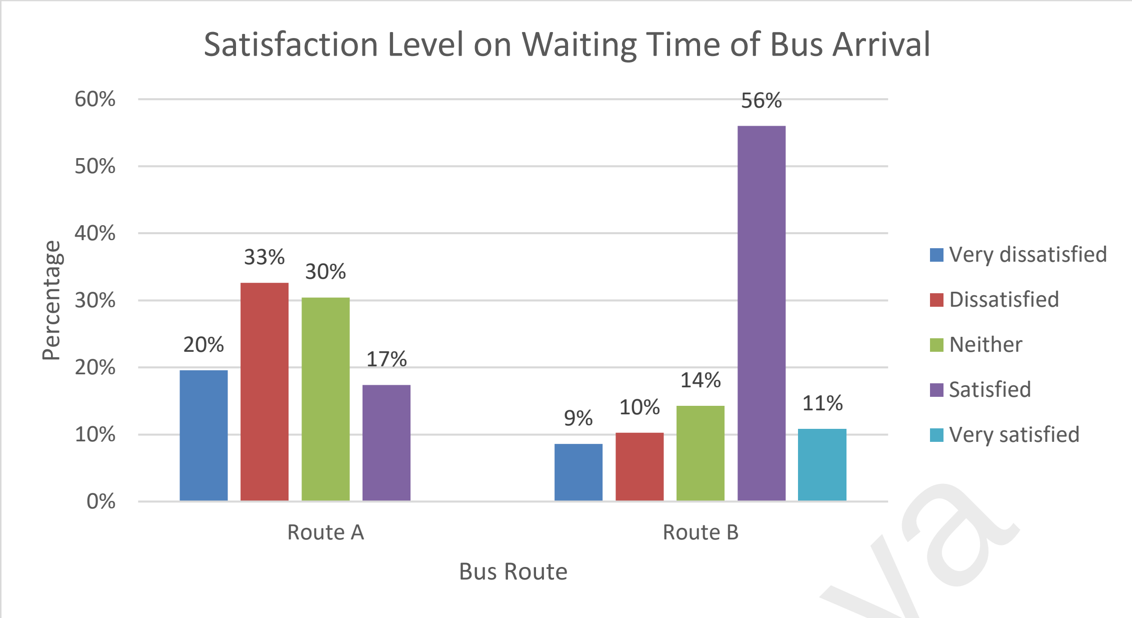

Figure 4.25: Satisfaction level on waiting time of bus arrival

For Bus Route A, about one-third of the respondents are dissatisfied with the current bus arrival waiting time while 30% of the respondents are neither satisfied nor dissatisfied with the current waiting time. For Bus Route B, more than half of the respondents are satisfied with the current bus arrival waiting duration. The satisfaction level of the current bus arrival waiting time on Bus Route A is only 17% lower than Bus Route B.

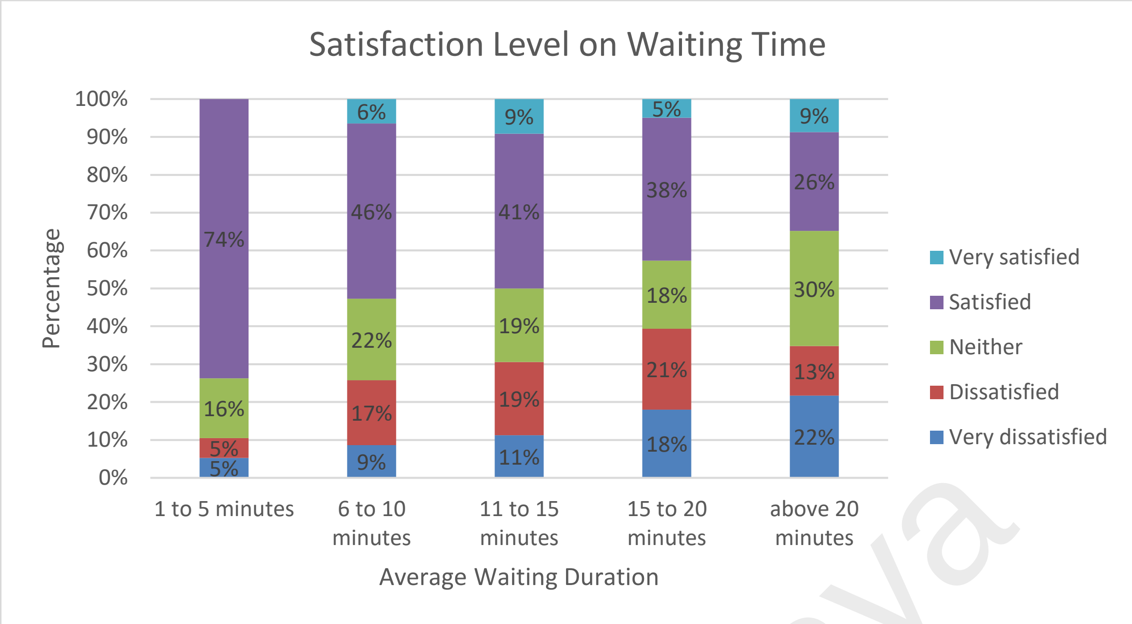

Figure 4.26: Satisfaction level on waiting time

Figure 4.26 shows the analysis of the satisfaction levels on the waiting time of bus arrival that have been classified into different classes of waiting duration. From Figure 4.26, the ceiling average waiting duration of bus arrival is 15 minutes. Nearly three quarters of the respondents that experienced an average waiting duration of less than five minutes are satisfied with the current bus arrival waiting time. There are 52% of the respondents who are satisfied or very satisfied with the current average waiting duration of between six and 10 minutes. In the group where the average waiting duration is 11 to 15 minutes, 50% of them are satisfied or very satisfied with the current bus arrival waiting time. From these three average waiting duration classes, at least half of the respondents are satisfied with the current bus arrival waiting time.

Only 43% and 37% of the respondents are satisfied with the current bus arrival waiting time of 15 to 20 minutes and above 20 minutes respectively. The distribution of satisfactory level of the bus arrival waiting time can be divided into two groups, which are less than 15 minutes and more than 15 minutes. Hence, the maximum bus arrival waiting duration that is acceptable among UM students is 15 minutes.

4.1.3.3 Overall bus service quality on different bus routes

Figure 4.27 shows the overall rating of bus service quality on different bus routes. Most of the respondents from Bus Route A are neither satisfied nor dissatisfied with the quality of the bus service.

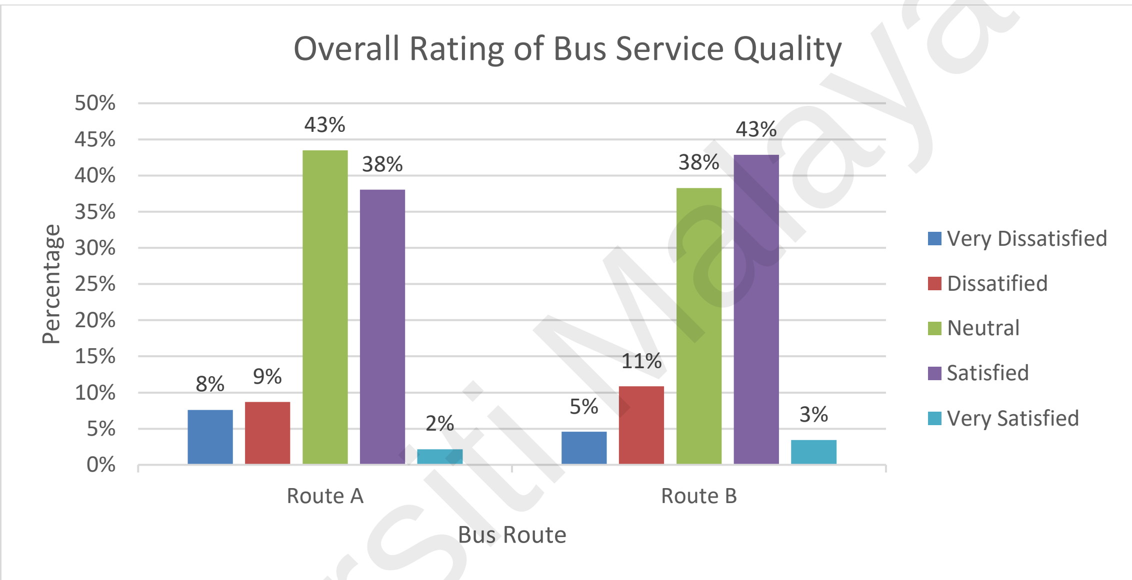

Figure 4.27: Overall rating of bus service quality

From Figure 4.27, there are 43% of Bus Route A respondents who are neither satisfied nor dissatisfied with the quality of the current UM bus service. On the other hand, there are 43% of Bus Route B respondents who are satisfied with the current bus service and 3% who are very satisfied with it. The respondents that are satisfied on Bus Route A is slightly lower than Bus Route B, at 38% of the respondents. Overall, we can conclude that the overall bus service rating of Bus Route B is higher than Bus Route A.

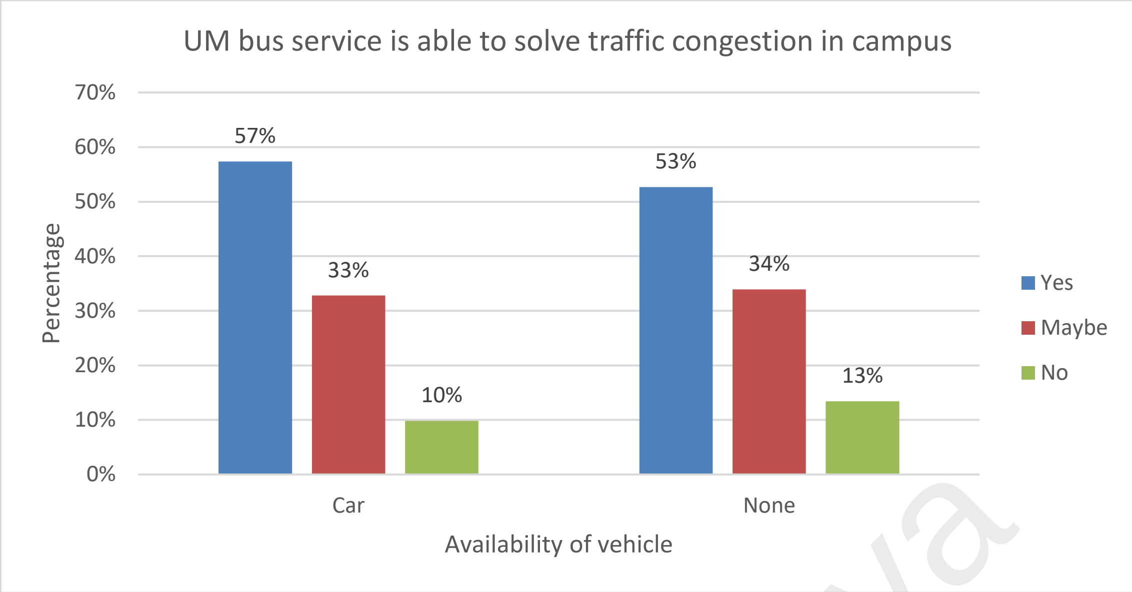

Figure 4.28: Solving traffic congestion in campus using UM campus bus service

Figure 4.28 shows respondents' opinion on using the campus bus service as a solution to the traffic congestion in campus. More than half of the respondents who are car owners agree that the UM campus bus service is the solution to solve traffic congestion on campus, whereas one-third of them have no opinion on this issue. Furthermore, 53% of the respondents without their own transportation also consider the campus bus service as a way to solve traffic congestion in campus. Only 10% of car owners and 13% of respondents without their own transportation do not agree with this solution.

4.1.4 Discussion

From the questionnaire survey, it is identified that the overall performance of Bus Route A has reached the minimum requirement with some flaws in terms of bus service and onboard crowdedness. It is undeniable that the service coverage area of Bus Route A is constrained by its geographical aspect whereby the coverage cannot be reduced. Instead of looking for a new route planning, an amendment to the bus timetable and number of bus trips should be the main concerns in improving the transit performance for Bus Route A.

The transit performance for Bus Route B is within acceptable range and can be further improved. From Figure 4.13, it is noticed that most of the respondents are overwhelmed with dissatisfaction on the driving quality, bus stop facilities, and bus reliability. Besides, it is obvious that the number of bus trips assigned on Bus Route B during peak hours is insufficient to cater to the passenger demand. Therefore, it is suggested that the bus timetable has to be revised and the person capacity improved to cater to the passenger demand.

The average waiting time of bus arrival for Bus Route A and Bus Route B are between 6 to 15 minutes, which falls in the acceptable range. Furthermore, more than half of the respondents raise the issue of overcrowded conditions in the bus for both routes and most of them suggest an increase in the bus service frequency or to modify the bus operating schedule.

Results also show that most of the respondents think that the congestion in campus is caused by the increased number of vehicles in campus. Only 44% of the respondents are satisfied or very satisfied with the current overall UM bus service. The waiting time for bus arrival can be further improved, but the overcrowded condition in the bus is the main complaint by the respondents.

4.2 Passenger Demand and Person Capacity Analysis

It is clear from the previous section that the questionnaire result shows that less than half of the respondents are satisfied with the overall campus bus service. The overcrowded condition in the buses is the main reason for low bus service satisfaction. The buses are full of passengers when they arrive at the stations during peak hours. From the comments by passengers in the questionnaire, the crowdedness situation on Bus Route B is worse than Bus Route A, especially during peak hours. Some of the passengers were not able to board the bus during peak hours when an overcrowded bus arrives at the station. They would need to wait 10 to 20 minutes for the following bus trip or travel to their destination by using other transportation modes. Respondents have suggested an increase in the frequency of the bus service as one of the recommendations to improve the current bus service.

To study the crowded condition on the bus, passenger load of a bus is identified and compared with the passenger capacity of the bus. The passenger demand and person capacity also need to be studied in detail throughout the observation period. The passenger demand of the transit bus service and its variations are important factors that influence the transit capacity, speed, and reliability. The passenger demand variation influences the ability of the bus operator in providing a good quality of bus service with the appropriate person capacity. In this section, the passenger demand distribution and person capacity are compared and the relationship between them is analysed by using PLF.

4.2.1 Passenger Demand Distribution Analysis

The passenger ridership is analysed on the bus trips between 8:00a.m. and 7:00p.m. and are grouped in hourly segments, which is the hourly passenger demand distribution throughout a day during the 11-hour observation period. The passenger demand distribution of both routes are tabulated separately on different graphs.

The trend of bus passenger ridership throughout the observation period, which is the passenger demand distribution, is used to identify the time period of peak passenger demand as well as off-peak passenger demand. The high passenger ridership resembles the peak demand of the transit bus whereas the low passenger ridership resembles the off-peak bus passenger demand. The passenger demand distribution is used to decide the person capacity. The time period with peak passenger ridership needs higher person capacity to cater to the demand whereas the time period with off-peak passenger ridership needs lower person capacity to cater to the demand. The passenger demand distribution of Bus Route A and Bus Route B are calculated and presented in Figure 4.29 and Figure 4.30.

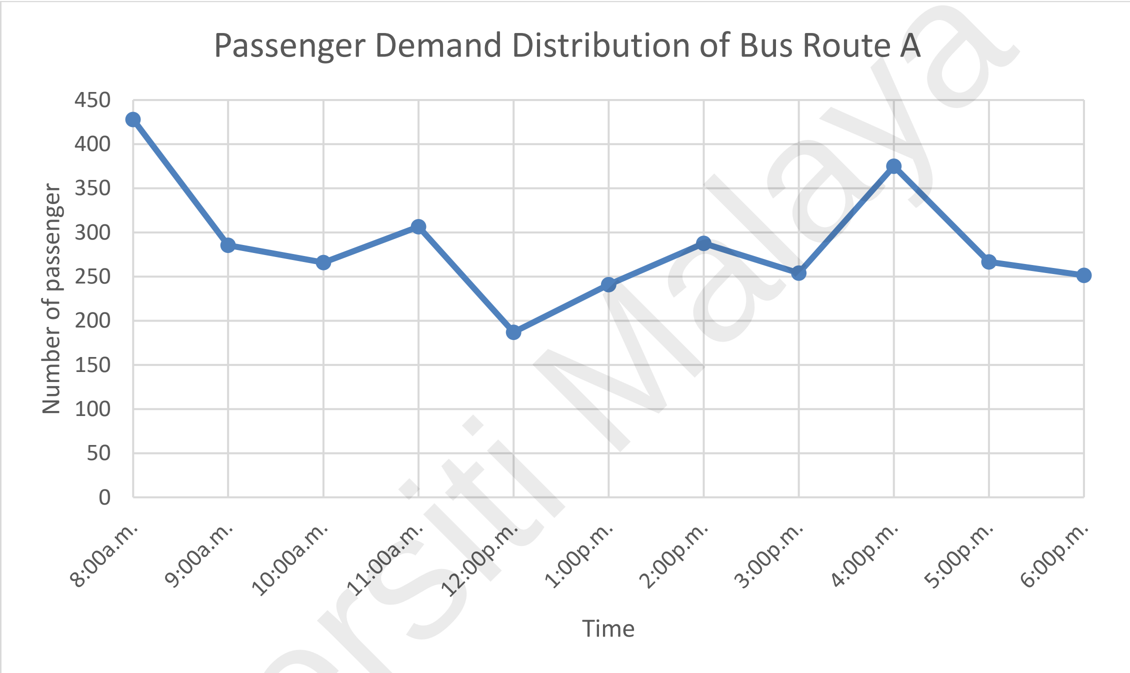

Figure 4.29: Time-of-day passenger demand distribution of Bus Route A

Figure 4.29 shows the time-of-day passenger demand distribution of Bus Route A. Bus Route A has two ridership peaks which occur during 8:00a.m. to 9:00a.m. and 4:00p.m. to 5:00p.m. The lowest passenger ridership happens during the period of 12:00p.m. to 1:00p.m. The peak demand on Bus Route A is relatively higher than its off-peak demand, with ridership during peak demand hour being 2.3 times higher than that of the off-peak demand hour. This passenger demand distribution shows that Bus Route A requires a high amount of peak-period-only bus trip to handle the high passenger ridership at specific stations during peak periods.

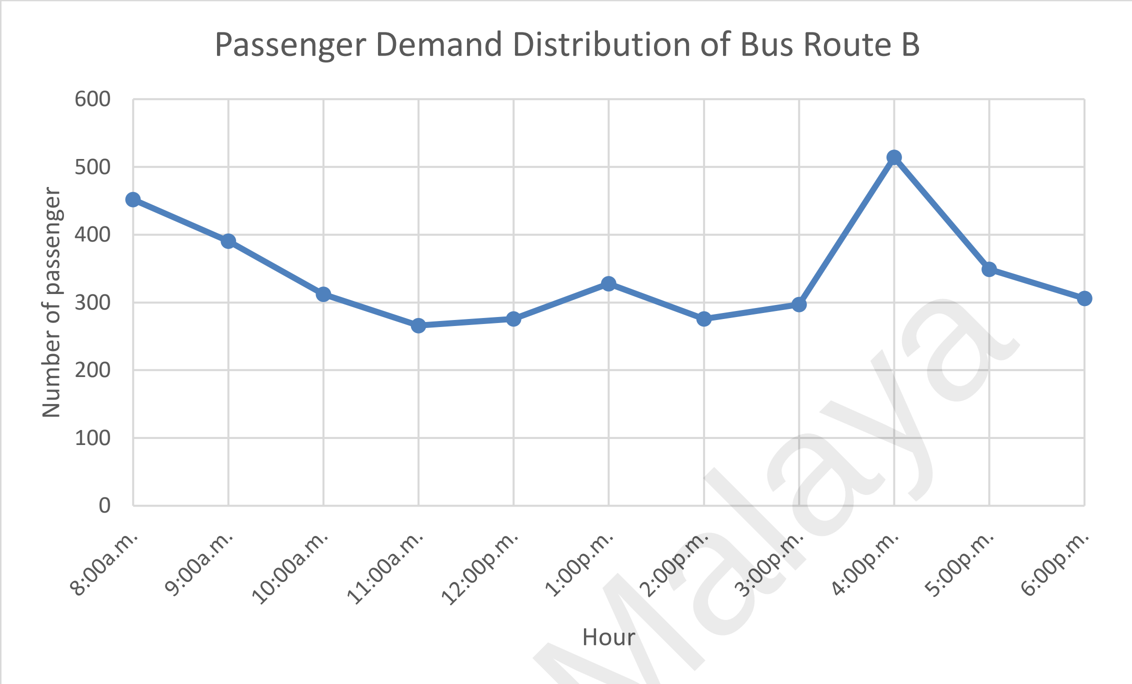

Figure 4.30: Time-of-day passenger demand distribution of Bus Route B

Figure 4.30 shows the time-of-day passenger demand distribution of Bus Route B. The passenger demand of Bus Route B has a sharp evening peak during 4:00p.m. to 5:00p.m. The morning peak of passenger ridership is during 8:00a.m. to 9:00a.m., which is the second highest passenger ridership throughout the observation period. The passenger demand decreases gradually from 9:00a.m. to 12:00p.m., whereby the lowest passenger demand throughout the day occurs from 11:00a.m. to 12:00p.m. Passenger demand remains stable and relatively low from 11:00a.m. till 4:00p.m. with a small afternoon peak between 1:00p.m. and 2:00p.m.

The passenger off-peak demand of Bus Route B is much closer to its peak demand with less fluctuation compared to that of Bus Route A. The ridership during peak demand hour is 1.9 times higher than the ridership during off-peak demand hour. Thus, the demand distribution reflects the passenger ridership on both commuting directions into the centre of university and students travelling back to residential colleges after class.

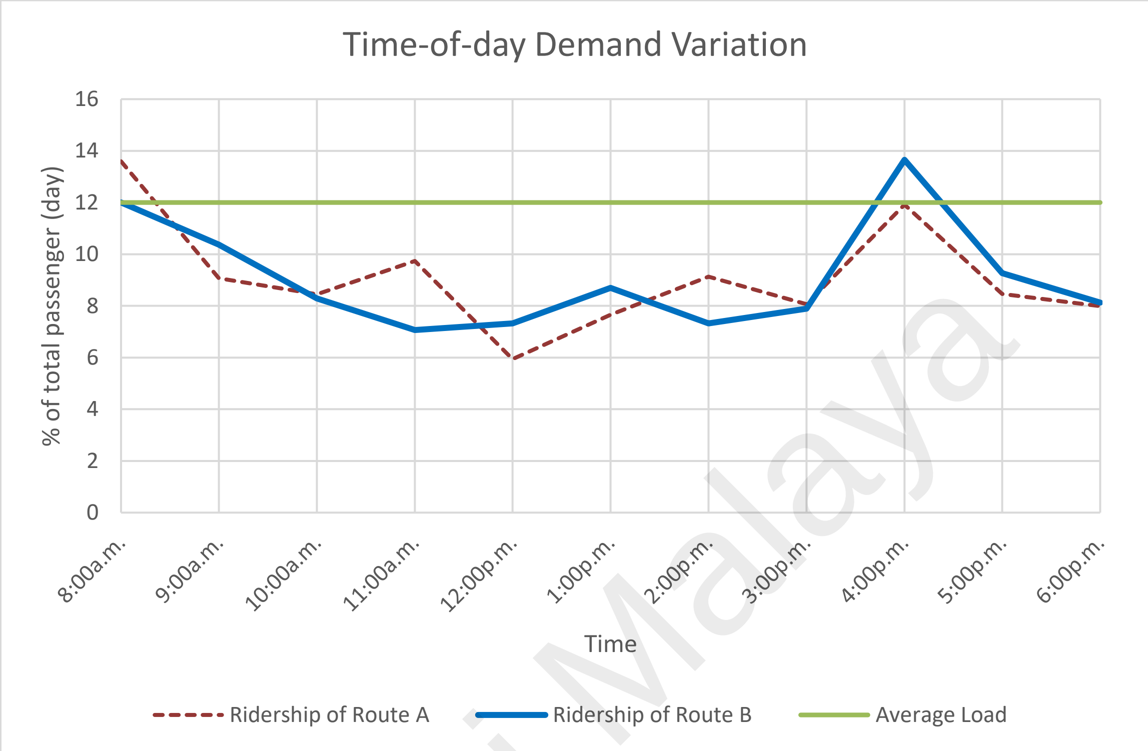

Figure 4.31: Time-of-day passenger demand variation in percentage

Figure 4.31 shows the passenger demand variation of both Bus Routes A and B. To have a good comparison of the ridership between both bus routes on the same scale, the percentage of hourly ridership to the whole day of passenger ridership is used. Despite the different sample sizes and number of ridership collected on different routes, both routes share the morning peak at 8:00a.m. to 9:00a.m. The passenger ridership of Bus Route A drops from 9:00a.m. to 11:00a.m. with a smaller peak demand during 11:00a.m. to 12:00p.m., whereas the ridership of Bus Route B decreases gradually from 9:00a.m. to 12:00p.m., with 11:00a.m. to 12:00p.m. showing minimum ridership for Bus Route B. The off-peak hour for Bus Route A is 12:00p.m. to 1:00p.m., with almost half the ridership of its morning peak. Bus Route B, on the other hand, has a small noon peak at

1:00p.m. to 2:00p.m. The hourly ridership between 2:00p.m. and 4:00p.m. is relatively constant between 200 and 300 ridership (0.07% to 0.1%) for both bus routes. Finally, both bus routes share the same evening peak hour at 4:00p.m. to 5:00p.m., followed by a sudden drop of ridership on both bus routes with Bus Route B having a higher percentage of demand than Bus Route A. These demand distributions illustrate several important points about the linkages between the passenger demand and service patterns (*TCQSM*, 2013).

4.2.1.1 Peak hour factor

The peak hour factor (PHF) concept is used to express the passenger demand variation within the peak hour. Figure 4.32 shows the passenger ridership data for the morning peak period for one day during observation at a peak demand station at the transportation hub in UM Campus. Demand for the peak 20 minutes of the peak hour was observed along with the average passenger demand during the peak periods. The PHF value during the morning peak hour is 0.713, which is considered medium-high and translates to relatively even passenger demand in the 20-minute intervals for the bus service of Bus Route A.

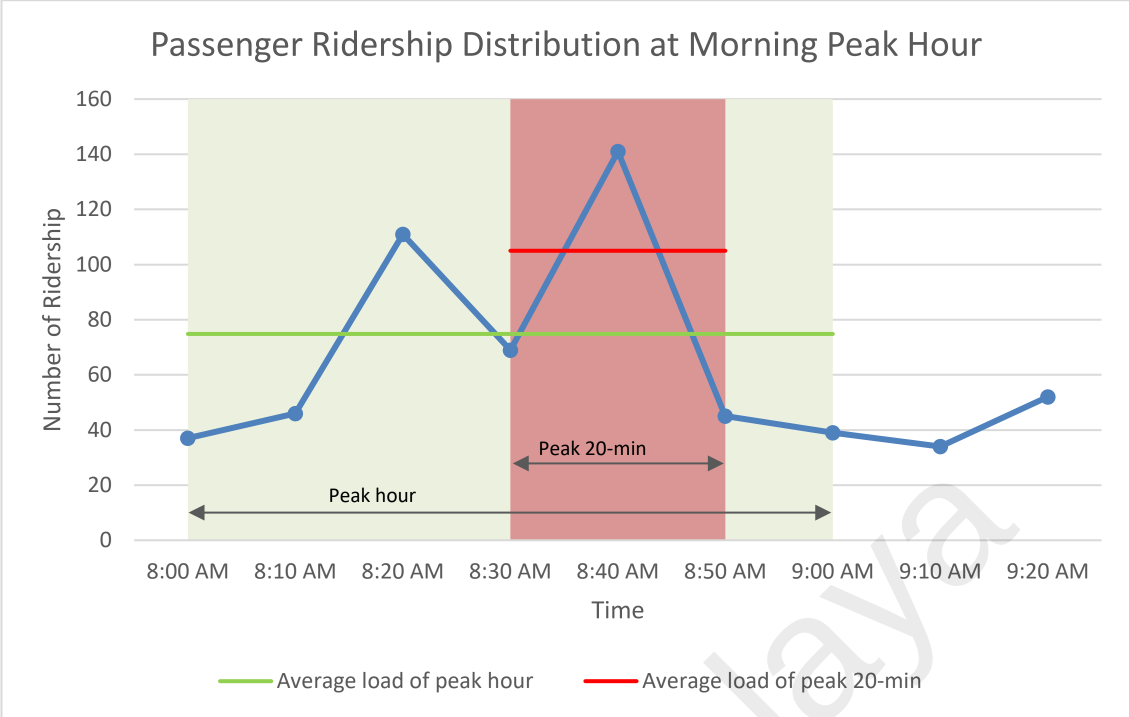

Figure 4.32: Variation on morning peak-hour demand of Bus Route A

There are vast variations between the highest ridership and lowest ridership in the morning peak hour with a difference of 281%, as shown in Figure 4.32. The bus trip that departs at 8:00a.m. has the lowest ridership with only 37 passengers, whereas the bus trip that departs at 8:40a.m. has the highest ridership with 141 passengers. Furthermore, the average load for the peak 20 minutes is 105 passengers per trip, which is higher than the average load for peak hour which is 74.8 passengers. The person capacity might satisfy the passenger ridership on the average peak hour load, but the passenger demand at the peak 20 minutes exceeds the person capacity.

Figure 4.33 shows the passenger ridership of the evening peak period for one day at a peak demand station at the transportation hub in UM Campus. The passenger demand for the peak hour and the peak 20 minutes are shown along with the average passenger demand during the peak hour. The PHF value during the evening peak hour is 0.951 which is relatively high. This means that the peak demand during the evening peak period is relatively even compared to the peak demand during the morning peak period. In many other cases, the proportional difference between the peak-hour and peak-20-minutes will be much greater than this situation.

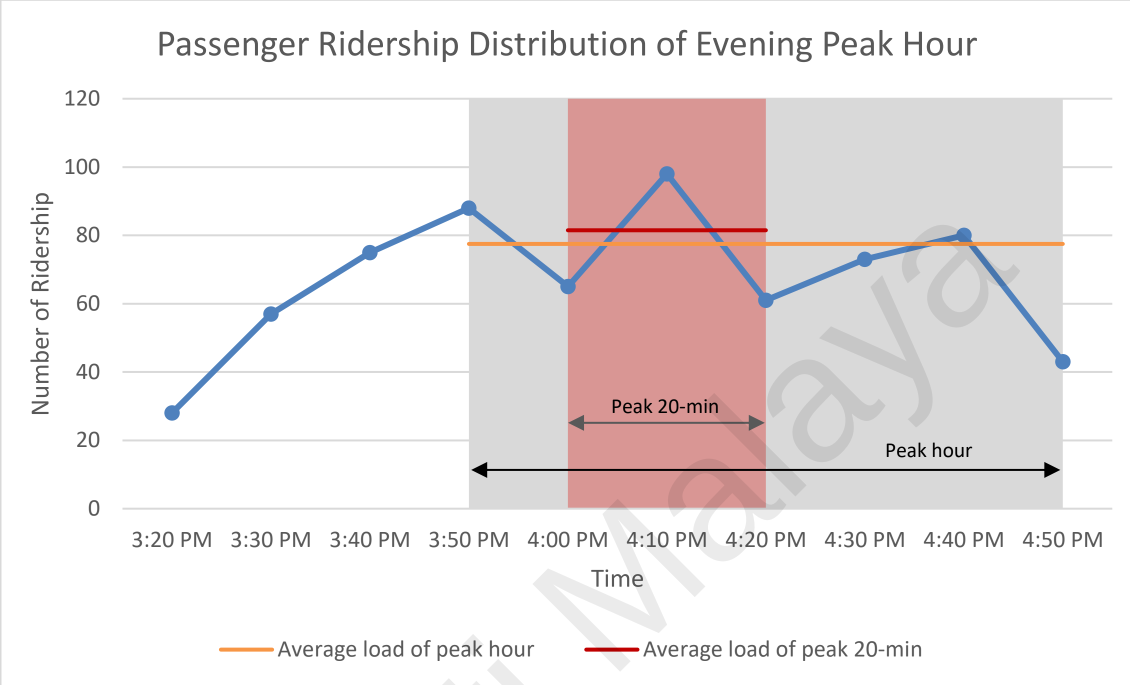

Figure 4.33: Variation on evening peak-hour demand of Bus Route A

It can be seen from Figure 4.33 that there is only a little variation between the highest ridership and lowest ridership during the evening peak hour between 3:50p.m. and 4:50p.m., with a difference of 61%. The bus trip that departs at 4:20p.m. has the lowest ridership with 61 passengers, whereas the bus trip that departs at 4:10p.m. has the highest ridership with 98 passengers. Furthermore, the average load during the peak 20 minutes is 81.5 passengers per trip, slightly higher than the average for the peak hour which is 77.5 passengers. The results from Figure 4.32 and Figure 4.33 show the importance of passenger demand variation in a peak hour. It is suggested that there should be extra bus trips for Bus Route A to cope with the short 20-mintute peak demand in the peak hour demand.

Figure 4.34 shows the passenger ridership data for the morning peak period for one day during observation at a peak demand station at the transportation hub in UM Campus, along with the peak hour and the peak 20 minutes and average passenger demand during the peak periods. The PHF value during the morning peak hour is 0.737, which is considered medium-high and indicates a relatively even passenger demand in the 20-minute intervals for the bus service of Bus Route B.

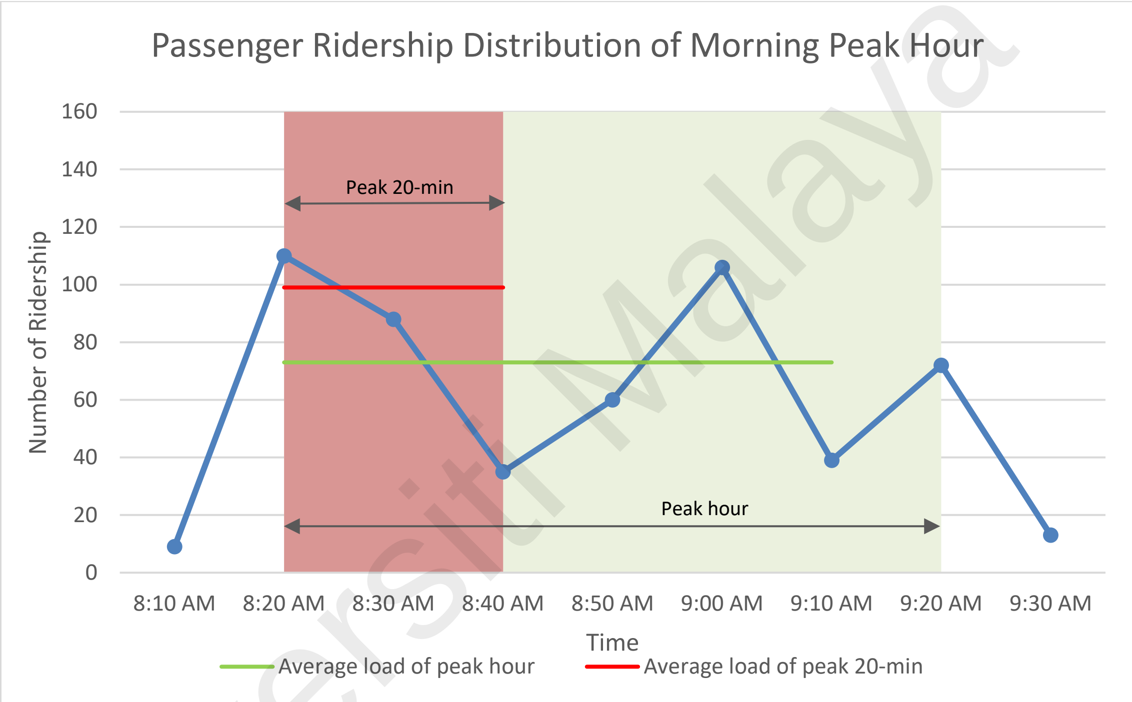

Figure 4.34: Variation on morning peak-hour demand of Bus Route B

There are vast variations between the highest ridership and lowest ridership in the morning peak hour with a difference of 214.29%, as shown in Figure 4.34. The bus trip that departs at 8:40a.m. has the lowest ridership with only 35 passengers, whereas the bus trip that departs at 8:20a.m. has the highest ridership with 110 passengers. Furthermore, the average load for the peak 20 minutes is 99 passengers per trip, higher than the average load for peak hour which is 73 passengers.

Figure 4.35 shows the passenger ridership of the evening peak period for one day at a peak demand station at the transportation hub in UM Campus. The passenger demand for the peak hour and the peak 20 minutes are shown along with the average passenger demand during the peak hour. The PHF value during the evening peak hour is 0.897 which is relatively high. This means the peak demand during the evening peak period is relatively even compared to the peak demand during the morning peak period.

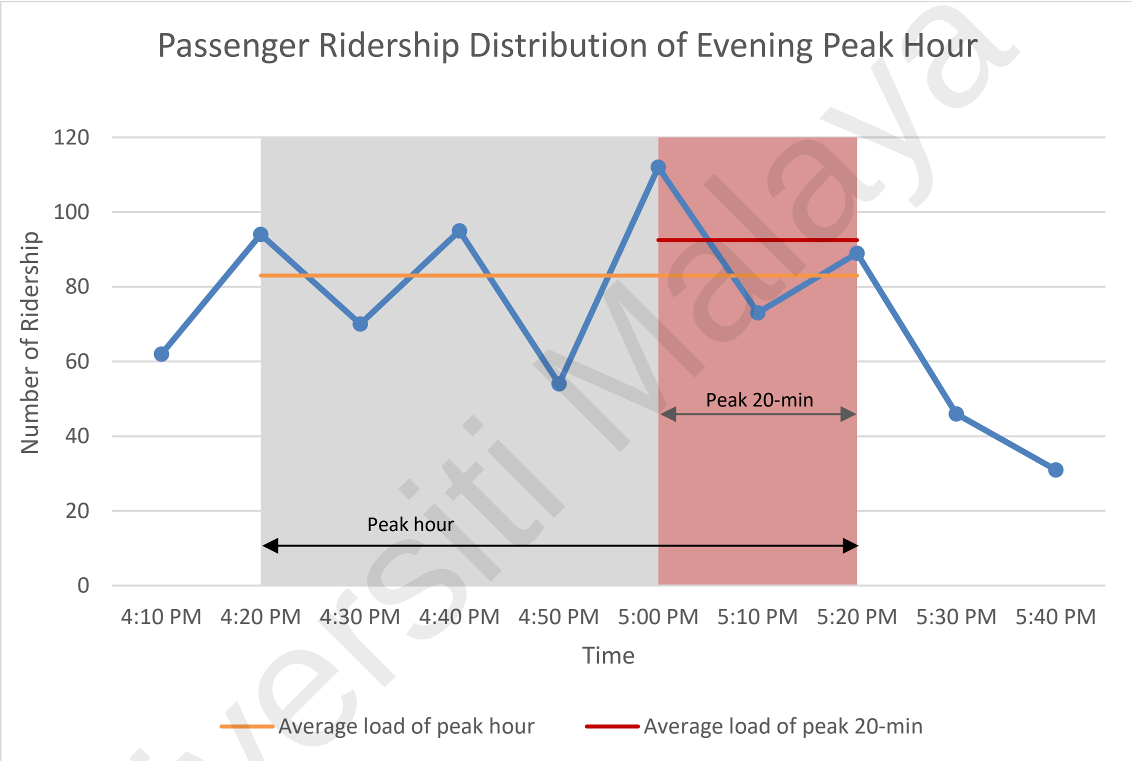

Figure 4.35: Variation on evening peak-hour demand of Bus Route B

Figure 4.35 shows that the differences between the highest ridership and lowest ridership in the evening peak hour (4:20p.m. to 5:20p.m.) is smaller than the morning peak hour, with a difference of 107%. The bus trip that departs at 4:50p.m. has the lowest ridership with 54 passengers, whereas the bus trip that departs at 5:00p.m. has the highest ridership with 112 passengers. Furthermore, the average load during the peak 20 minutes is 92.5 passengers per trip, slightly higher than the average for the peak hour which is 83 passengers. The results from Figure 4.34 and Figure 4.35 show the significant effects of passenger demand variation over the peak hour. Bus trips with even headway are not able to cater to passenger demand. A rearrangement of bus trip departure times or extra bus trips is suggested for the operator to cope with the short 20-mintute peak demand during the peak hour demand.

4.2.2 Person Capacity Analysis

The main purpose of the campus bus service is to move students around the campus. The study of the transit capacity is focused more on the number of people that can be served in a specific time period, which is the person capacity. There are two types of buses used for Bus Routes A and B which have been identified to have the respective maximum capacity as listed in Table 4.2.

Table 4.2: Bus type with corresponding maximum passenger capacity

Bus Type	Maximum Passenger Capacity (passenger)
One-door bus	40
Two-door bus	63

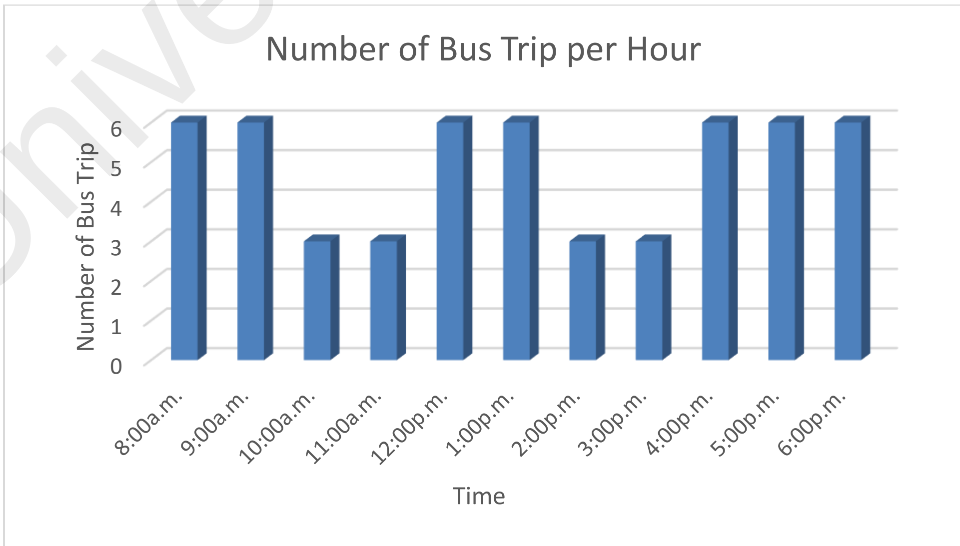

Figure 4.36: Number of bus trips departure

Figure 4.36 shows the number of bus departures throughout the observation period by the hour. The operation of both bus routes follow the peak hours that are defined by the Student Affairs Division of UM which lie within the time intervals of 8:20a.m. to 10:00a.m., 12:00p.m. to 2:00p.m., and 4:00p.m. to 7:00p.m. Two-door buses depart from the origin station with 20-minute headways, which is equivalent to three departures per hour. During peak hours, additional trips of one-door buses will depart from the origin station 10 minutes after the departure of the two-door bus. Figure 4.37 presents the total person capacity along with the passenger demand distribution of Bus Route A.

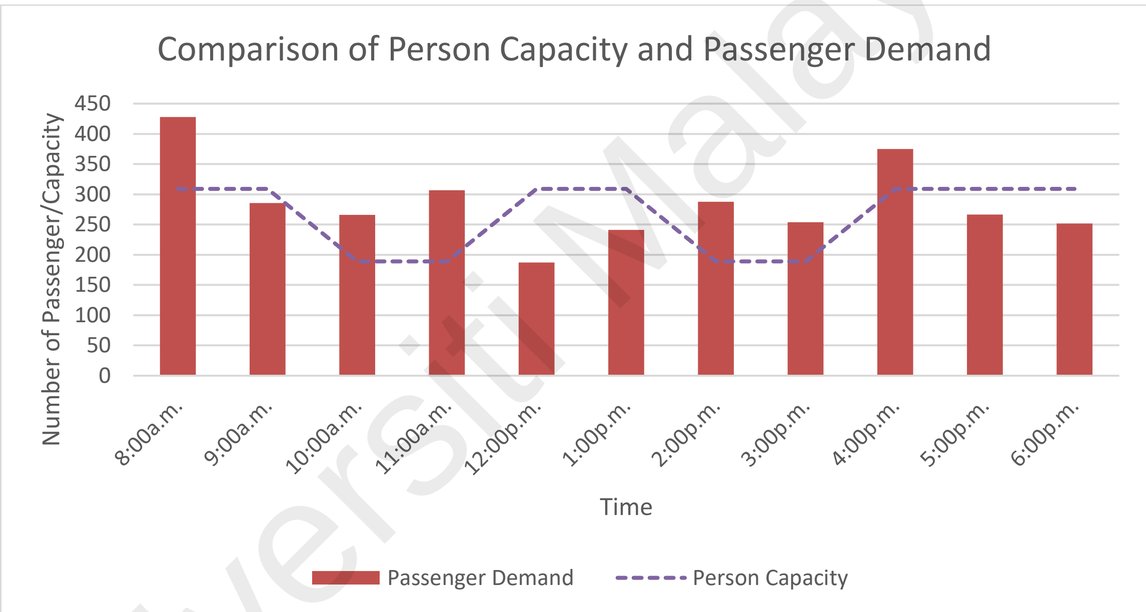

Figure 4.37: Comparison between person capacity and passenger demand of Bus Route A

Figure 4.37 shows that the person capacity during certain periods are not fully optimised, especially from 12:00p.m. to 1:00p.m. When it comes to the utilisation of bus resources, the bar chart in Figure 4.36, which represents passenger demand, should be lower than the line chart, which represents person capacity. Among the peak hours, person capacity was able to cope with passenger demand at 9:00a.m. to 10:00a.m. and 5:00p.m to 7:00p.m. However, there was an undersupply of person capacity (where demand is more than capacity) during the peak hours of 8:00a.m. to 9:00a.m. and 4:00p.m. to 5:00p.m., whereby the person capacity was not enough to cope with the peak demand. More bus trips are needed to increase the person capacity during these periods. On the other hand, there is an oversupply of person capacity at 12:00p.m. to 2:00p.m., where the person capacity is much higher than the passenger demand. All the non-peak hour periods also face the problem of undersupply of person capacity, such as from 10:00a.m. to 12:00p.m. and 2:00p.m. to 4:00p.m.

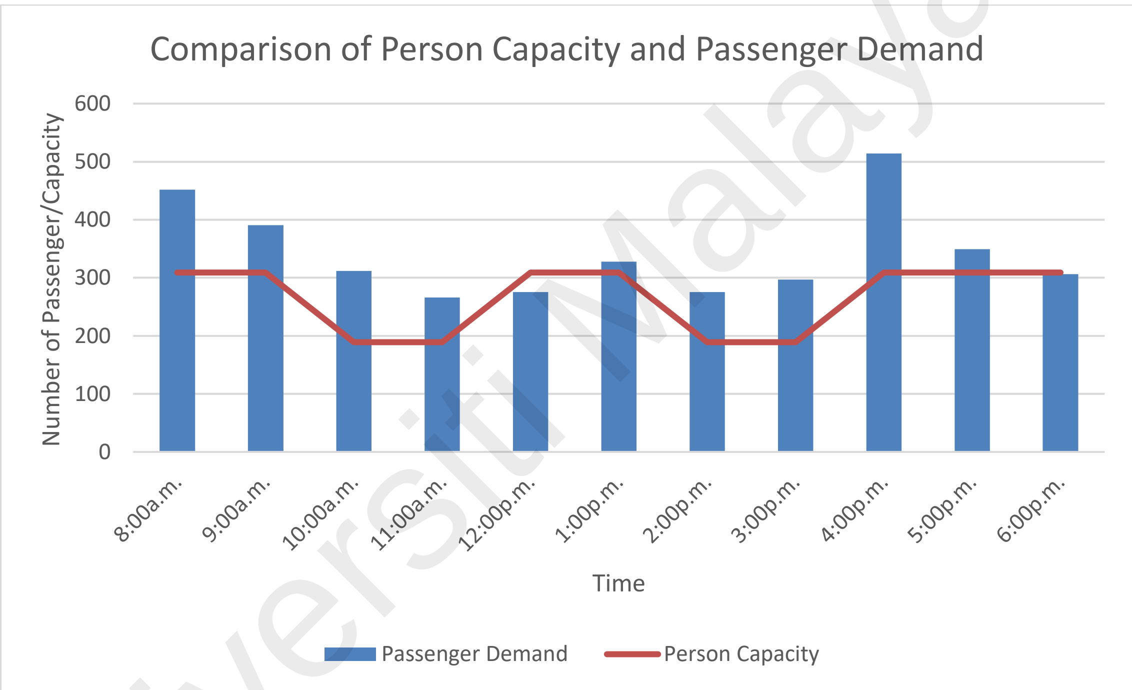

Figure 4.38: Comparison between person capacity and passenger demand of Bus Route B

Figure 4.38 shows the passenger demand distribution and person capacity for Bus Route B. It clearly shows that the undersupply of person capacity on Bus Route B is worse than Bus Route A. The person capacity was not enough to cope with passenger ridership most of the time, even during the off-peak hours. This clearly shows that the person capacity was only able to cater to the passenger demand at 12:00p.m. to 1:00p.m. and 6:00p.m. to 7:00p.m., whereby both time intervals fall within the peak hours.

Undersupply of person capacity happens during the peak hours, as well as off-peak hours. A parameter is needed to measure the ability of person capacity that satisfies the passenger demand. Furthermore, the capacity ceiling during off-peak hours should be identified to avoid wastage of resources for operators. PLF is used to justify these situations and is discussed in the following section.

4.2.3 Passenger Load Factor Analysis

Passenger demand and person capacity were discussed in the previous sections and are interrelated with each other. The person capacity should be higher than the passenger demand to avoid an undersupply of person capacity. At the same time, the person capacity should not be too much higher than the passenger demand to avoid wastage of resources. Passenger load factor is a parameter used to study the relationship between passenger demand and person capacity and to show the crowdedness condition in a bus.

PLF is the ratio of the number of passengers on-board to the maximum passenger capacity of the vehicle during a certain section on a trip. PLF represents the index of passenger occupancy after boarding and alighting activities are done, before the bus stops at the following station (Demery Jr, 2005). A bus trip with PLF >1.0 means that the onboard overloaded situation has happened in a bus at a certain station of a trip, whereby person capacity is not enough to cater to the passenger ridership at that particular time section.

From Figure 4.39, the time intervals with relatively high PLF bus trips occur during 8:00a.m. to 9:00a.m., 11:00a.m. to 12:00p.m., 3:00p.m. to 4:00p.m., and 4:00p.m. to 5:00p.m. Meanwhile, time sections with relatively low PLF bus trips occur during 10:00a.m. to 11:00a.m., 12:00p.m. to 1:00p.m., and 1:00p.m. to 2:00p.m.

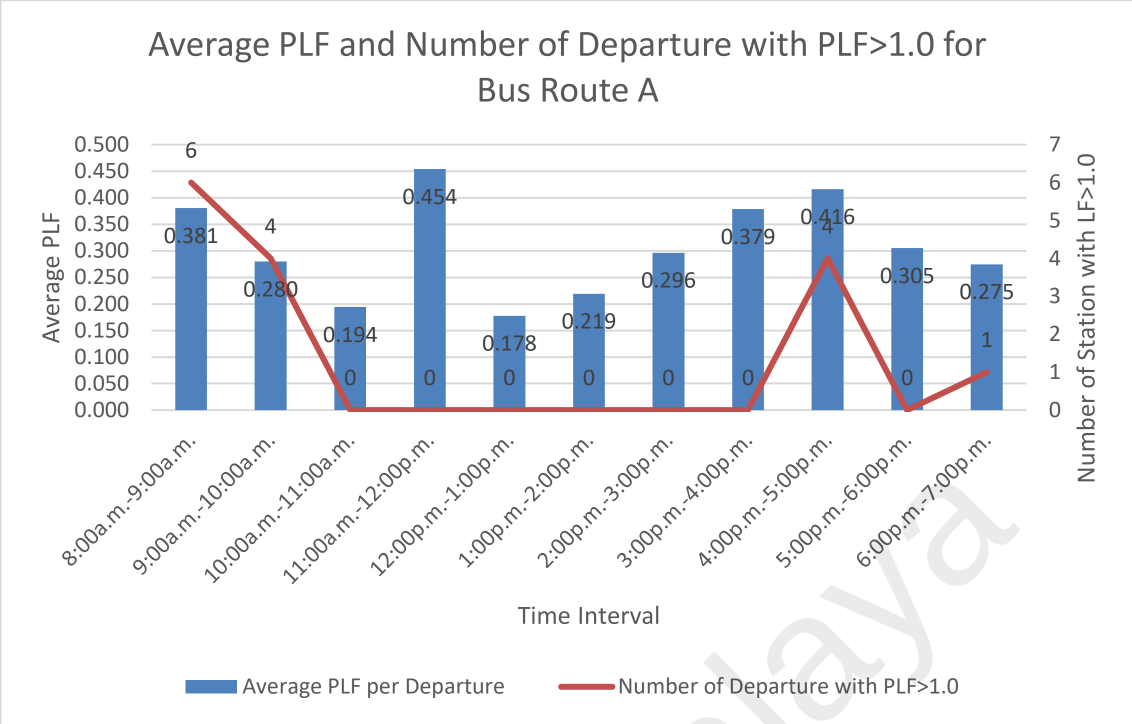

Figure 4.39: Average PLF per bus and number of bus trip with PLF>1.0 for Bus Route A

For periods 8:00a.m. to 9:00a.m., 9:00a.m. to 10:00a.m., 4:00p.m. to 5:00p.m., and 6:00p.m. to 7:00p.m., the calculation shows a situation of bus overload. In terms of the number of bus departures with PLF>1.0, it can be observed that the overloaded situation on a bus is closely associated with peak demand periods. This indicates that the person capacity during these periods is insufficient to cope with the peak passenger demand and eventually leads to a situation of congestion onboard and an overloaded bus. More bus trips need to be assigned during peak demand periods to avoid overloaded buses. However, one interesting situation that can be observed is that although the period of 11:00a.m. to 12:00p.m. has the highest ridership throughout the observation period, yet the situation of overload does not occur. This means that there is ample person capacity during this period to cope with the passenger ridership.

Since there are multiple trips and there is a high possibility of demand fluctuation within an hour, the value obtained from Figure 4.39 above might level out the passenger demand variation, which is inadequate to express the actual passenger demand. To investigate the PLF on peak-hour demand variation, it is crucial to study the bus trips in the peak hour, if possible, or to identify the peak of the peak by using PHF in Section 4.2.1.1.

The PLF analysis of Bus Route B is shown in Figure 4.40. The bus trips with relatively high PLF happens during 9:00a.m. to 10:00a.m., 10:00a.m. to 11:00a.m., 11:00a.m. to 12:00p.m., 4:00p.m. to 5:00p.m., and 5:00p.m. to 6:00p.m. Meanwhile, the bus trips with low PLF per departure occurs at 12:00p.m. to 1:00p.m., 1:00p.m. to 2:00p.m., and 2:00p.m. to 3:00p.m.

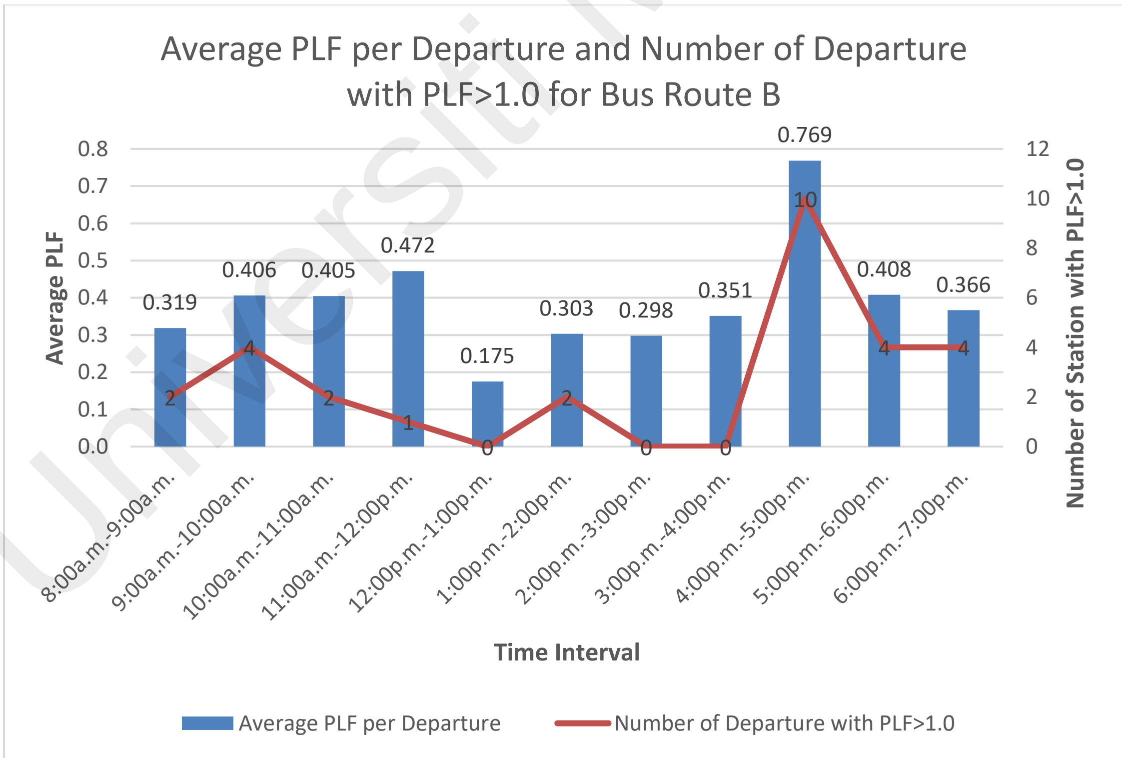

Figure 4.40: Average PLF per bus and number of bus trip with PLF>1.0 for Bus Route B

In terms of the number of bus trips with PLF>1.0, it can be observed that the overloaded situation in Bus Route B is worse than Bus Route A which occurs from 8:00a.m. to 12:00p.m., 1:00p.m. to 2:00p.m., and 4:00p.m. to 7:00p.m. The occurrence of this situation does not only happen during periods with high passenger demand, but also during off-peak hours such as 10:00a.m. to 12:00p.m. The result indicates that Bus Route B has more serious overloaded problems during peak passenger demand periods, where the person capacity is greatly insufficient to accommodate the passenger ridership. The PLF analysis for every hour is summarised in Appendix E for the overall performance of the bus service.

4.2.4 Discussion

Peak hour definition is very crucial in transit bus operation to assign enough person capacity to cope with passenger demand. By understanding the distribution of passenger ridership throughout the service period and by identifying the peak and off-peak hour, a transit bus operator is able to adjust the number of bus departures accordingly, which affects the person capacity of certain time intervals, particularly the number of buses in operation and the bus type used to cater to the passenger ridership. Literature review suggests that the peak hour with extra person capacity should be in accordance to the peak passenger demand observed (Abreha, 2007; Hale & Charles, 2010; Ólafsdóttír, 2012). The current peak hour defined by Student Affairs Department lies within the time intervals of 8:00a.m. to 10:00a.m., 12:00p.m. to 2:00p.m., and 4:00p.m. to 7:00p.m. The distribution of passenger ridership is compared with the defined peak hours to assess the congruency of the current bus schedule.

4.2.4.1 Bus Route A

The result of Bus Route A observations is summarised in Table 4.3. Table 4.3 shows that the person capacity of the transit bus service does not fully match with passenger demand.

Table 4.3: Analysis result for Bus Route A

Time Interval	Ridership of bus (%)	High average PLF	Low average PLF	Bus departure with PLF>1.0
8:00-9:00a.m.	11	*		*
9:00-10:00a.m.	7			*
10:00-11:00a.m.	5		*	
11:00a.m.-12:00p.m.	16	*		
12:00-1:00p.m.	5		*	
1:00-2:00p.m.	6		*	
2:00-3:00p.m.	9			
3:00-4:00p.m.	13	*		
4:00-5:00p.m.	12	*		*
5:00-6:00p.m.	8			
6:00-7:00p.m.	8			*

When there is a situation of low ridership and low average PLF but still some bus departures are overloaded, it means that the bus trips are not assigned according to the passenger demand. A possible reason for this occurrence could be that the passenger demand is not distributed evenly throughout that particular hour, such as the periods of 9:00a.m. to 10:00a.m., 10:00a.m. to 11:00a.m., and 1:00p.m. to 2:00p.m.

The time intervals of 11:00a.m. to 12:00p.m. and 3:00p.m. to 4:00p.m. have recorded relatively high passenger ridership and PLF, which do not lie within the current peak hours with higher person capacity. On the other hand, the time intervals of 12:00p.m.. to 1:00p.m. and 1:00p.m. to 2:00p.m. fall within the current peak hours but have relatively low passenger ridership and PLF. The bus overload condition occurs during the periods of 8:00a.m. to 10:00a.m., 4:00p.m. to 5:00p.m. and 6:00p.m. to 7:00p.m., which means the high person capacity with six bus departures per hour were not able to cope with the peak passenger demand.

Apart from the imbalance of passenger demand and person capacity of transit supply, Appendix D and Appendix E show the existence of bus overload for both bus routes during the peak hour, indicating that the current person capacity is insufficient to accommodate the existing peak passenger demand. The passenger demand distribution also shows that the person capacity does not match the passenger ridership, where there is oversupplied of person capacity during the afternoon peak hour, from 12:00p.m. to 2:00p.m. Table 4.4 shows the percentage of ridership which have been grouped according to the peak hour intervals in the current bus timetable.

Table 4.4: Percentage of ridership with current peak hour for Bus Route A

Time Interval	Ridership (%)	Grouping of Ridership (%)
8:00-9:00a.m.	11	18
9:00-10:00a.m.	7	
10:00-11:00a.m.	5	5
11:00a.m.-12:00p.m.	16	16
12:00-1:00p.m.	5	11
1:00-2:00p.m.	6	
2:00-3:00p.m.	9	9
3:00-4:00p.m.	13	13
4:00-5:00p.m.	12	28
5:00-6:00p.m.	8	
6:00-7:00p.m.	8	

From observation, only 11% of total passenger ridership throughout the observation period lies within the 12:00p.m. to 2:00p.m. period. On the other hand, 18% and 28% of total passenger ridership fall into the morning peak hours of 8:00a.m. to 10:00a.m. and evening peak hours of 4:00p.m. to 7:00p.m. respectively. It is suggested that the high person capacity during the noon peak hours be reassigned to the other periods with higher passenger ridership. The person capacity during off-peak hours with high passenger ridership such as 11:00a.m. to 12:00p.m. and 3:00p.m. to 4:00p.m. need to be reallocated to cope with passenger demand.

4.2.4.2 Bus Route B

The result of Bus Route B observations is summarised in Table 4.5. Table 4.5 shows that the person capacity of the transit bus service does not fully match with the passenger demand.

Table 4.5: Analysis result for Bus Route B

Time Interval	Ridership of bus (%)	High PLF	Low PLF	Bus departure with PLF>1.0
8:00-9:00a.m.	11			*
9:00-10:00a.m.	10	*		*
10:00-11:00a.m.	10	*		*
11:00a.m.-12:00p.m.	12	*		*
12:00-1:00p.m.	4		*	
1:00-2:00p.m.	6		*	*
2:00-3:00p.m.	7		*	
3:00-4:00p.m.	9			
4:00-5:00p.m.	15	*		*
5:00-6:00p.m.	9	*		*
6:00-7:00p.m.	7			*

From Table 4.5, the analysis outcome for Bus Route B displays the similar observation as Bus Route A, where the person capacity does not fully fit the actual transit passenger demand. Relatively high ridership and PLF are recorded during the time interval of 11:00a.m. to 12:00p.m. which does not lie within the peak hour of person capacity, while the time intervals of 12:00p.m. to 1:00p.m. and 6:00p.m. to 7:00p.m. have relatively low ridership and PLF which lie within the peak hour of higher person capacity. Bus Route B has more time intervals with overloaded conditions compared to Bus Route A, signifying that the person capacity of the current bus schedule is critically insufficient. Besides, the peak hour with higher person capacity is not carefully assigned along with peak passenger demand. Only 10% of the overall ridership lies within the 12:00p.m. to 2:00p.m. period, whereby the person capacity is inadequate. Table 4.6 shows the percentage of ridership that has been grouped according to the current peak hour intervals.

Table 4.6: Percentage of ridership with current peak hour for Bus Route B

<table>
<tr><th>Time Interval</th><th>Ridership (%)</th><th>Grouping of Ridership (%)</th></tr>
<tr><td>8:00-9:00a.m.</td><td>11</td><td rowspan="2">21</td></tr>
<tr><td>9:00-10:00a.m.</td><td>10</td></tr>
<tr><td>10:00-11:00a.m.</td><td>10</td><td>10</td></tr>
<tr><td>11:00a.m.-12:00p.m.</td><td>12</td><td>12</td></tr>
<tr><td>12:00-1:00p.m.</td><td>4</td><td rowspan="2">10</td></tr>
<tr><td>1:00-2:00p.m.</td><td>6</td></tr>
<tr><td>2:00-3:00p.m.</td><td>7</td><td>7</td></tr>
<tr><td>3:00-4:00p.m.</td><td>9</td><td>9</td></tr>
<tr><td>4:00-5:00p.m.</td><td>15</td><td rowspan="3">31</td></tr>
<tr><td>5:00-6:00p.m.</td><td>9</td></tr>
<tr><td>6:00-7:00p.m.</td><td>7</td></tr>
</table>

From observation, only 10% of total passenger ridership throughout the observation period lies within the 12:00p.m. to 2:00p.m. period, similar to Bus Route A. On the other hand, 21% and 31% of total passenger ridership lie within the morning peak hours of 8:00a.m. to 10:00a.m. and evening peak hours of 4:00p.m. to 7:00p.m. respectively. The high person capacity during the noon peak hours need to be reassigned and the number of operating bus trips reduced. The person capacity during off-peak hours with high passenger demand such as from 10:00a.m. to 11:00a.m., 11:00a.m. to 12:00p.m., and 3:00p.m. to 4:00p.m. need to be reallocated to cope with the passenger demand.

4.3 Dwell Time Model

It is clear from the previous section that the passenger demand of transit bus service and its variations are important factors that influence the transit capacity, speed, and reliability. The passenger demand also influences the bus operator's ability to provide a good quality of bus service. It is important to analyse the bus travel time, especially from the operator’s perspective. Travel time is a crucial factor when scheduling a bus route timetable. By reducing the trip time, the transit speed is improved. If the travel time is realistic, then the fleet size can be optimised which results in lower operational costs.

Trip time is the combination of running time and dwell time. Running time is the time of bus travel at a trip section between two adjacent stops whereas dwell time is the time of a bus stopping at a station. The analysis shows that the running time at each section is rather consistent and the effects by other factors, such as traffic condition are less significant. Therefore, the variation of total trip time is mainly contributed by the variability of dwell time. The focus of this section is to identify the factors affecting dwell time, in order to provide a better bus timetable.

Descriptive statistic is carried out before a linear regression analysis to have an overview of the observations collected from passenger count data. Descriptive analysis provides a brief summary of the collected sample observation and the measure done on this dwell time study. The bus dwell time ($DWELL$) is the duration when the bus is completely stopped at a station in the unit of seconds. Dwell time is modelled against the following variables: the number of boarding passenger ($BOARD$), the number of alighting passenger ($ALIGHT$), the type of bus used (BUS), and the location of the stop at a transportation hub (TH). Table 4.7 shows the descriptive statistic on the observations collected.

Table 4.7: Descriptive statistic of bus dwell time

Variables	Mean	Standard Deviation
Dwell Time ($DWELL$)	20.680 (sec/station)	18.5
Boarding Passenger ($BOARD$)	7.245 (pax/station)	10.7
Alighting Passenger ($ALIGHT$)	7.593 (pax/station)	12.6
Passenger Load Factor (PLF)	0.327 (per station)	0.272

Table 4.7 the descriptive statistics of all variables used in the dwell time model analysis. The average of bus dwell time is 20.68 seconds per station, with a standard

deviation of 18.5 seconds. The number of boarding and alighting passengers at a bus station averages at 7.245 and 7.593 passengers per station respectively, which means that there are about seven passengers boarding and eight passenger alighting at a bus station for on-campus bus routes on average. The mean PLF is 0.327 per station, with a standard deviation of 0.272. The $DWELL$, $BOARD$, $ALIGHT$ and PLF are continuous variables whereas both TH and BUS are binomial categorical variables. Both categorical variables are binary data and hence, a dummy variable is used to represent TH and BUS in the multiple linear regression analysis. For the variable TH, the transportation hub station is represented by the value "1" and all other bus stations are represented by the value "0". For the variable BUS, the one-door bus and two-door bus are represented by the values of "1" and "0" respectively.

The mean dwell time with standard deviation at each bus station for both Bus Route A and Bus Route B are shown in Figure 4.41 and Figure 4.42 respectively. Note that the origin and end terminals do not have any dwell time and therefore not included in the figures below.

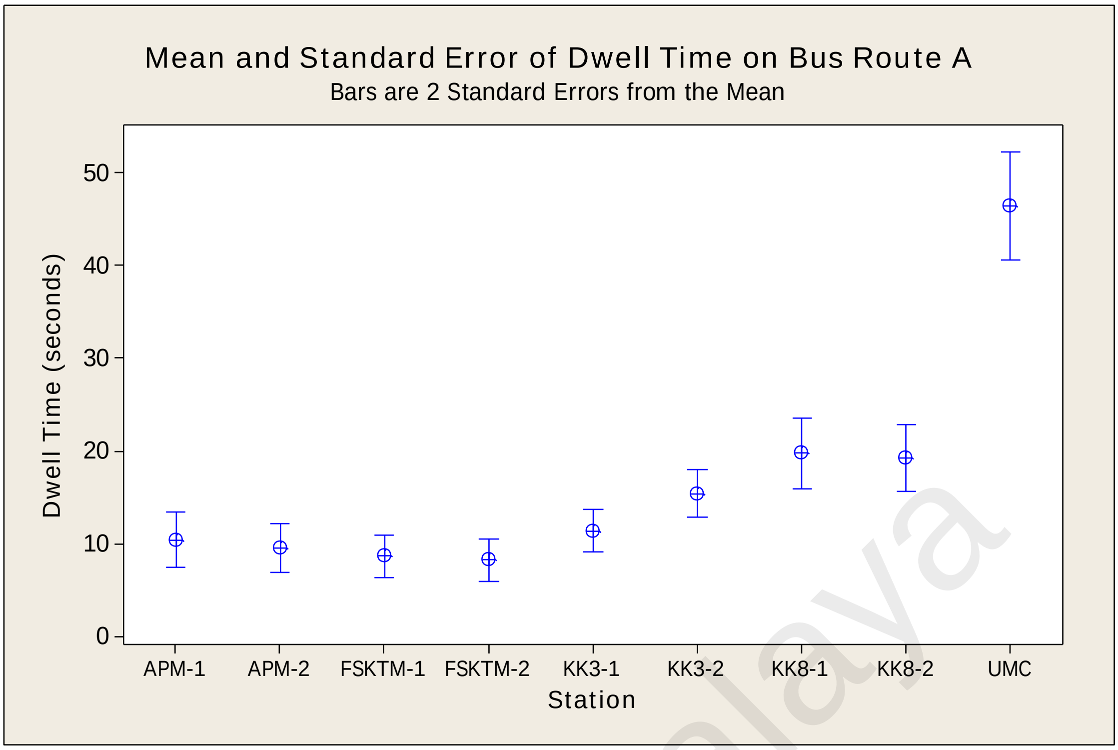

Figure 4.41: Mean dwell time and variation on all stations of Bus Route A

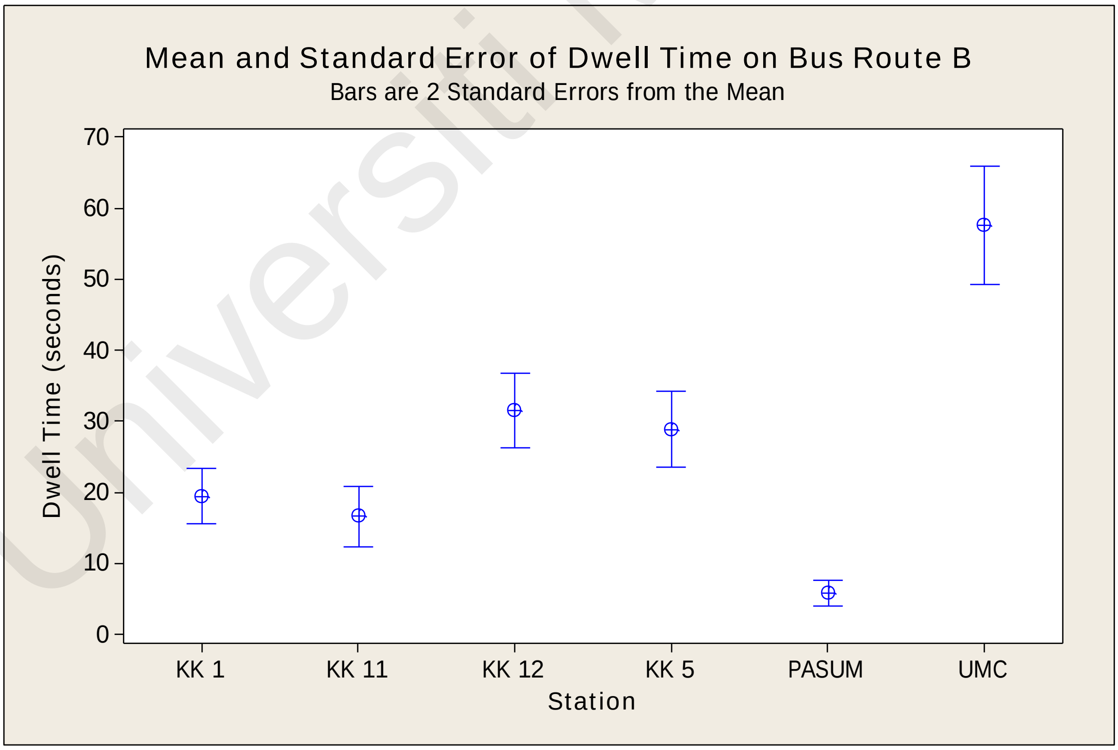

Figure 4.42: Mean dwell time and variation on all stations of Bus Route B

From Figure 4.41 and Figure 4.42, the mean dwell time at the UMC station is higher than other stations. The UMC station which is the transportation hub has the longest average mean dwell time and highest standard deviation for both bus routes. It shows that a bus tends to stop longer at the transportation hub with high variation of dwell time compared to the other bus stations. This could be explained by the high passenger activity at the transportation hub, which is presented in the Section 4.3.3.

4.3.1 General Dwell Time Model

The general form of dwell time model by using multiple linear regression analysis is assumed to have the following form based on the equation below (*TCQSM*, 2013; Washington et al., 2010):

$$DWELL = \beta_1 BOARD + \beta_2 ALIGHT + c_0 + \varepsilon \quad \textbf{4.1}$$

where

$DWELL$ = the dwell time per stop (seconds);

$BOARD$ = the number of boarding passenger (passenger/stop);

$ALIGHT$ = the number of alighting passenger (passenger/stop);

β_1 = coefficients of $BOARD$;

β_2 = coefficients of $ALIGHT$;

c_0 = constant (seconds);

ε = error term (residual).

In this equation, $DWELL$ is the dependent variable while $BOARD$ and $ALIGHT$ are the independent variables. The value β_1 and β_2 are the regression coefficients in seconds estimated by using ordinary least square (OLS) estimator. It should be noted here that for a given bus trip, the coefficient of constant term of a model can be explained as the operation time of the door open and door close. In this regression model, the number of boarding passenger and the number of alighting passenger at a bus station are studied as the governing variables to the bus dwell time. The general dwell time model is generated to obtain the coefficients with the passenger count data. This general dwell time model will be used to compare with another dwell time model with additional factors which contribute other specific effects to the dwell time.

The assumptions of multiple linear regression analysis on general dwell time model are full filled as shown in Figure 4.43, Figure 4.44, and Figure 4.45.

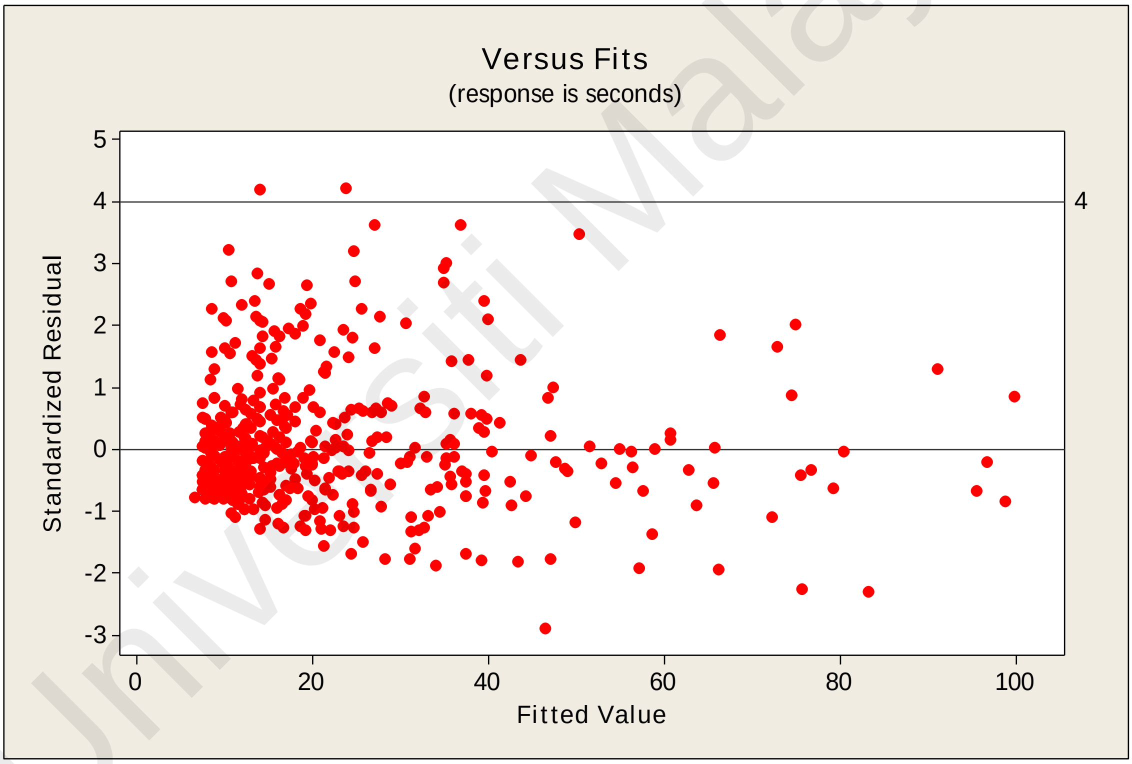

Figure 4.43: Scatterplot of fitted value vs. standardized residual

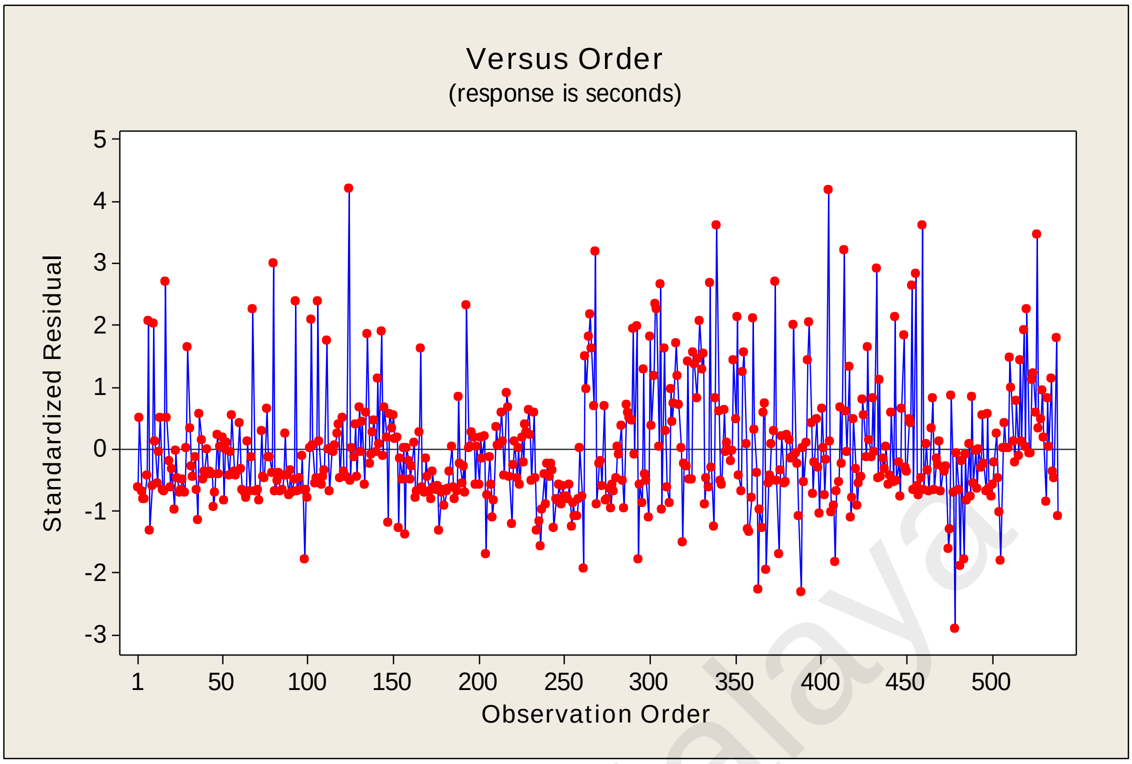

Figure 4.44: Scatterplot of observation order with standardized residual

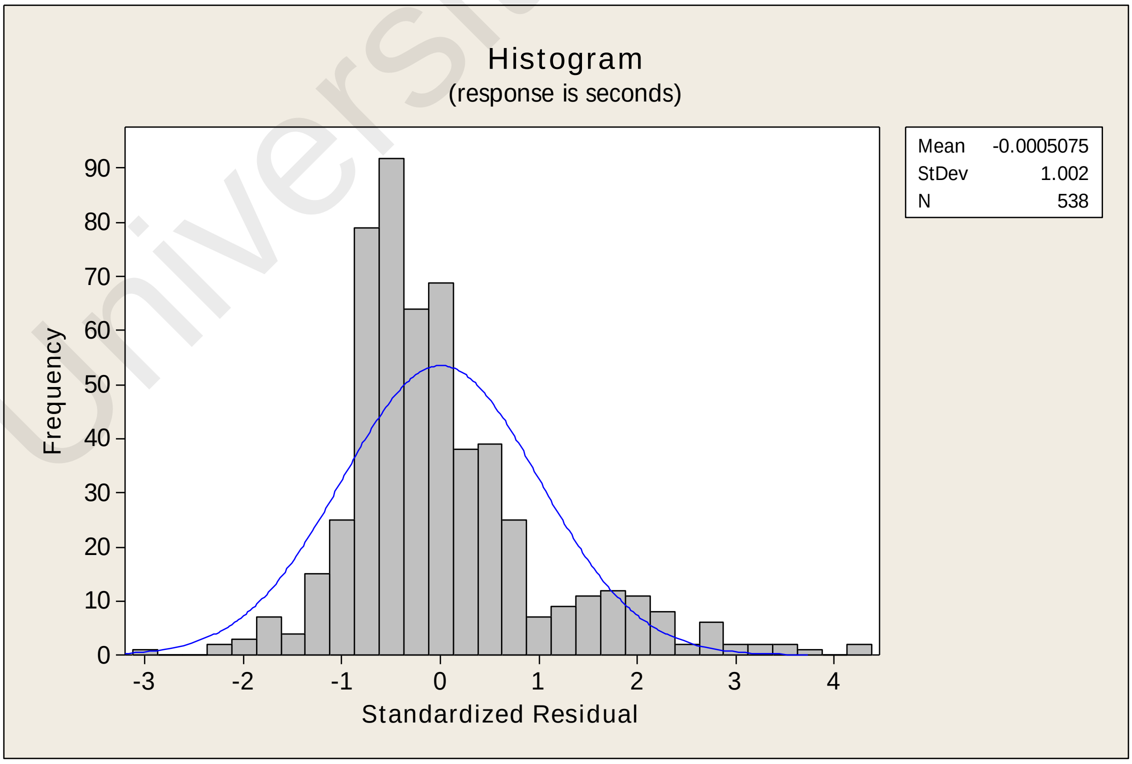

Figure 4.45: Histogram of standardized residual

Figure 4.43 shows that almost all the standardized residual points are within the range [-4, 4]. Figure 4.44 shows the standardized residuals have no trend and no autocorrelation effect. Figure 4.45 shows that the distribution of standardized residual is closed to normal distribution with the mean value of almost 0.

Table 4.8 presents the result of the general dwell time model from the multiple linear regression analysis. This general dwell time model is defined and explained by the number of boarding passengers ($BOARD$) and the number of alighting passengers ($ALIGHT$) only.

Table 4.8: Result of general bus dwell time model

Variable	Coefficient	Standard Error	T-statistic	VIF
$BOARD$	1.058	0.0351	30.16	1.025
$ALIGHT$	0.818	0.0298	27.50	1.025
c_0	6.799	0.4837	14.06	-
Adjusted R-squared	78.6	-	-	-

*All variables have 99% significant level.

The result indicates that each boarding and alighting passenger adds 1.058 and 0.818 seconds respectively to the base dwell time (c_0) of 6.799 seconds. The bus door opening and closing operation are part of the base dwell time (c_0). All the coefficients are highly significant and with the adjusted R-squared value of 78.6.

4.3.2 Effects of Dwell Time Model: Transportation Hub, Bus Type and PLF

4.3.2.1 Transportation hub effect

The transportation hub is the interchange station for passenger where all the campus bus routes are stop at this bus station. The mean dwell time at transportation hub is considerably longer than other stations. Table 4.9 shows the comparison of dwell time in transportation hub and other stations.

Table 4.9: Means of bus dwell time

Dwell Time	Mean (seconds)	Standard Deviation	N
Observation at transportation hub	51.90	21.45	68
Observation at other stations	16.165	12.822	470
Overall observation	20.680	18.50	538

The mean dwell time for the observation at transportation hub is 51.90 seconds averagely, about 150% more than the mean of overall dwell time observation; while the mean dwell time for the observation at other stations is just 16.165 seconds averagely, only 22% less than the mean of overall dwell time observation. This is expected, as UM Central Station is the main transportation hub on UM Campus. All bus serving the UM campus bus routes and other intercity bus routes at Kuala Lumpur will stop at this main interchange station. Dummy variable is used in the dwell time model to differentiate the effect between bus stopping at transportation hub and other bus stations.

4.3.2.2 Bus type effect

There are two types of buses that are used for on-campus bus routes, which are one-door bus and two-door bus. The one-door buses are 12m long with a capacity of 40 passengers without standing capacity, high floor design, and three-step stairs at the only one entrance. The two-door buses are 12m long bus with a capacity of 63 passengers, low floor design, including 40 seats and 23 standees. The two-door bus serves the bus route three trips in an hour throughout the operating hours, whereas the one-door bus serves during peak hour periods only, which are 8:00a.m. to 10:00a.m., 12:00p.m. to 2:00p.m., and 4:00p.m. to 7:00p.m.

To have a better view on bus type effects, the dwell time per passenger is calculated, which is the average time taken for a passenger to board on a bus or alight from a bus (L. Sun, Tirachini, Axhausen, Erath, & Lee, 2014). By carrying out this calculation, there will be a clearer view of the effect of bus type used on the time taken for a boarding or alighting passenger, as well as the dwell time at each station. The mean of dwell time per passenger is divided by the bus type category as shown in Table 4.10.

Table 4.10: Average dwell time of each passenger on different bus type

Dwell Time per Passenger	Mean (seconds)	Standard Deviation	N
Observation on two-door bus	1.876	16.579	415
Observation on one-door bus	3.431	2.413	123
Overall observation	2.232	1.9674	538

The mean dwell time per passenger for the observation on one-door bus is 3.431 seconds, about 54% more than the mean of overall observation, while mean dwell time per passenger for the observation on two-door bus is just 1.876 seconds, 16% less than the mean of overall observation. This situation is look reasonable, as one-door bus has only one entrance and high staircase at entrance. It takes more time for a boarding or alighting passenger to enter or leave the bus, comparing with two-door bus has low floor design and two entrances.

4.3.2.3 Passenger load factor effect

PLF indicates the bus occupancy level at a station before passenger activity occurs. A scatter plot and a Pearson's product-moment correlation were used to determine the relationship between dwell time and PLF. The first step in performing the regression analysis is to examine the trend of the two variables by using scatter plot. Figure 4.46 shows the scatter plot of dwell time vs. PLF. The plots on the graph look widely spread but there is a little noticed trend here where the dwell time moves higher when the PLF value is higher.

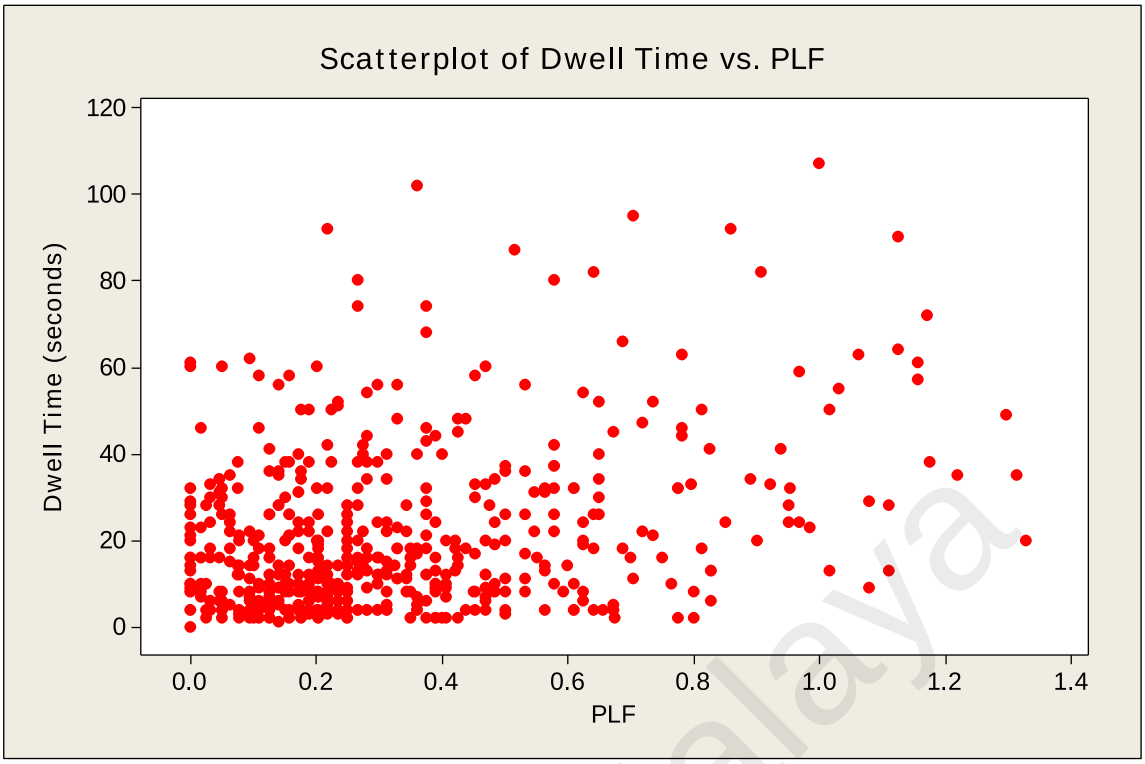

Figure 4.46: Scatterplot of bus dwell time vs. PLF

The correlation between dwell time and PLF was tested with Pearson correlation to confirm the trend from the scatter plot. The Pearson correlation coefficient of dwell time and PLF is 0.337 with p-value of less than 0.001. Figure 4.46 and the Pearson correlation coefficient show that a medium positive correlation between dwell time and PLF is observed with a strong evidence. The result form Pearson correlation has strong evidence with medium positive correlation, yet there is significant outliers shows in Figure 4.46 at low PLF area. There are some sample data show long dwell time with low PLF value. These outliers with long dwell time are caused by other dwell time factors and are removed from dwell time regression analysis.

The relationship of dwell time and PLF is investigated in the next section by generating regression models, along with dwell time factors such as transportation hub and type of bus used. The best dwell time model is identified by using best subset analysis.

4.3.3 Best Dwell Time Model using Best Subset Regression Analysis

In the previous section, the mean of dwell time in different categories show that there are transportation hub and bus type effects on the dwell time model. Moreover, the scatter plot of dwell time with PLF and Pearson coefficient also proves that the bus dwell time is weakly affected by the PLF. The dwell time correlates with PLF weakly, but there is strongly evidence that the PLF has a highly significant effect on dwell time (p-value less than 0.001). In this section, the dwell time model is generated by using best subset regression analysis to identify the best dwell time model with the combination of dwell time factors. The best dwell time model has the highest explanatory power on dwell time with the combination of selected dwell time factors.

Best subset regression analysis is used to identify the best dwell time model with the combination of given dwell time factors. The values of the adjusted R-squared ($\overline{R^2}$) and Mallow's C_p are used to identify the best dwell time model among all the generated models with different combination of factors. The model with the highest $\overline{R^2}$ value and the least C_p value is the best model with highest explanatory power on dwell time. Table 4.11 shows the list of generated models with all possible combination of factors and Figure 4.47 plots the adjusted R-squared and C_p values of all generated dwell time models.

Table 4.11: Result of best subset regression analysis

No	R-squared	Adjusted R-squared	Mallows' C_p	Boarding	Alighting	UMC	BUS	PLF
1	78.7	78.6	175.9	*	*			
2	82.1	82.0	62.5	*	*	*		
3	81.0	80.9	101.1	*	*		*	
4	78.7	78.6	177.8	*	*			*
5	83.8	83.7	8.9	*	*	*	*	
6	82.3	82.2	59.2	*	*	*		*
7	81.0	80.8	103.1	*	*		*	*
8	84.0	83.8	6.0	*	*	*	*	*

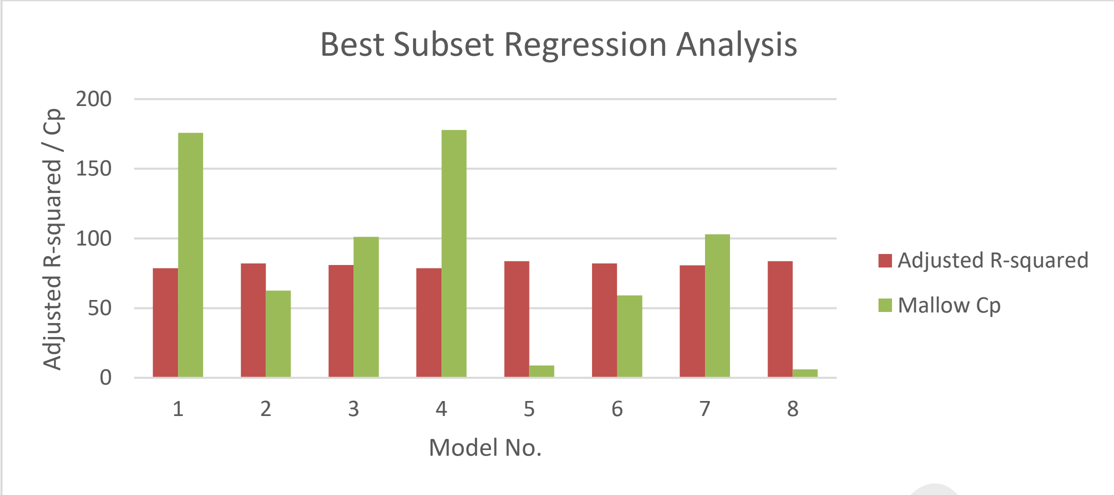

Figure 4.47: Adjusted R-squared and Mallows' C_p values for all dwell time models

Table 4.11 and Figure 4.47 shows that the best dwell time model is Model 8, with the highest adjusted R-squared value of 83.8 and lowest C_p value of 6.0. Result shows that the best dwell time model with the highest explanatory power is the model with all five predicted factors, which are number of boarding passengers ($BOARD$), number of alighting passengers ($ALIGHT$), transportation hub (TH), type of bus used (BUS) and passenger load factor (PLF). Model 8 is chosen to perform the multiple linear regression analysis and check the validity of this model with the assumptions of regression analysis. Model 8 full fills the multiple linear regression analysis assumptions as shown in Figure 4.48, Figure 4.49, and Figure 4.50.

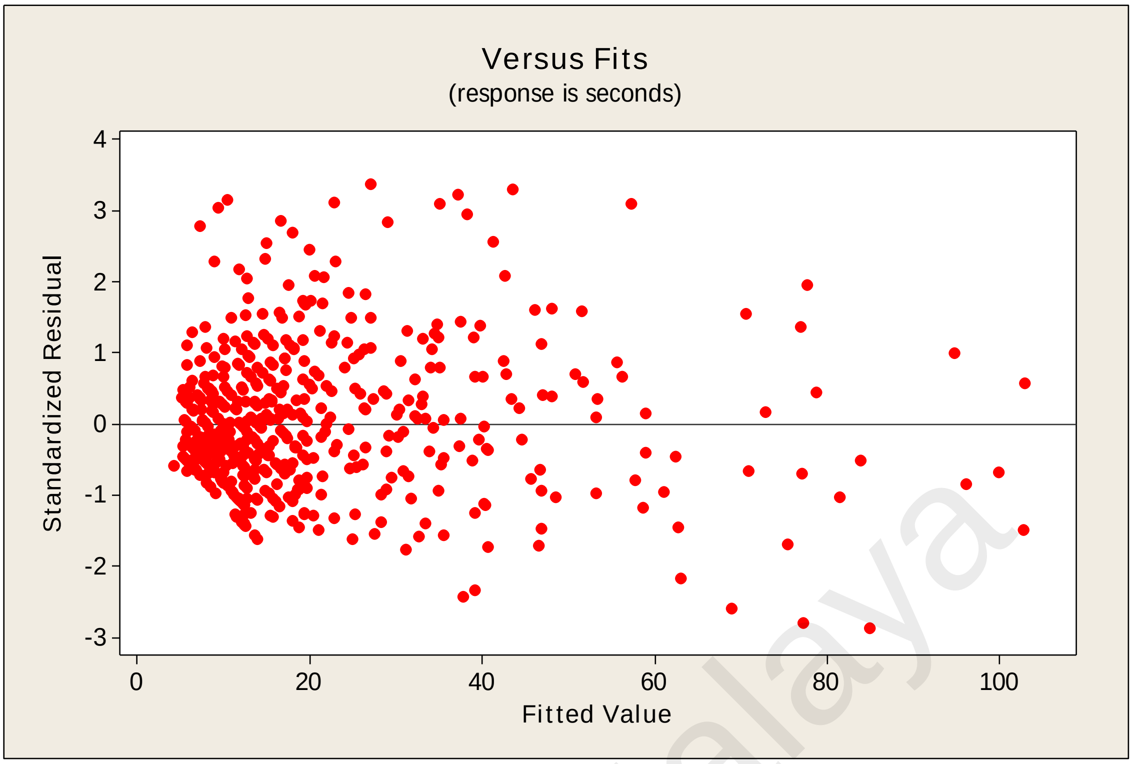

Figure 4.48: Scatterplot of fitted value vs. standardized residual

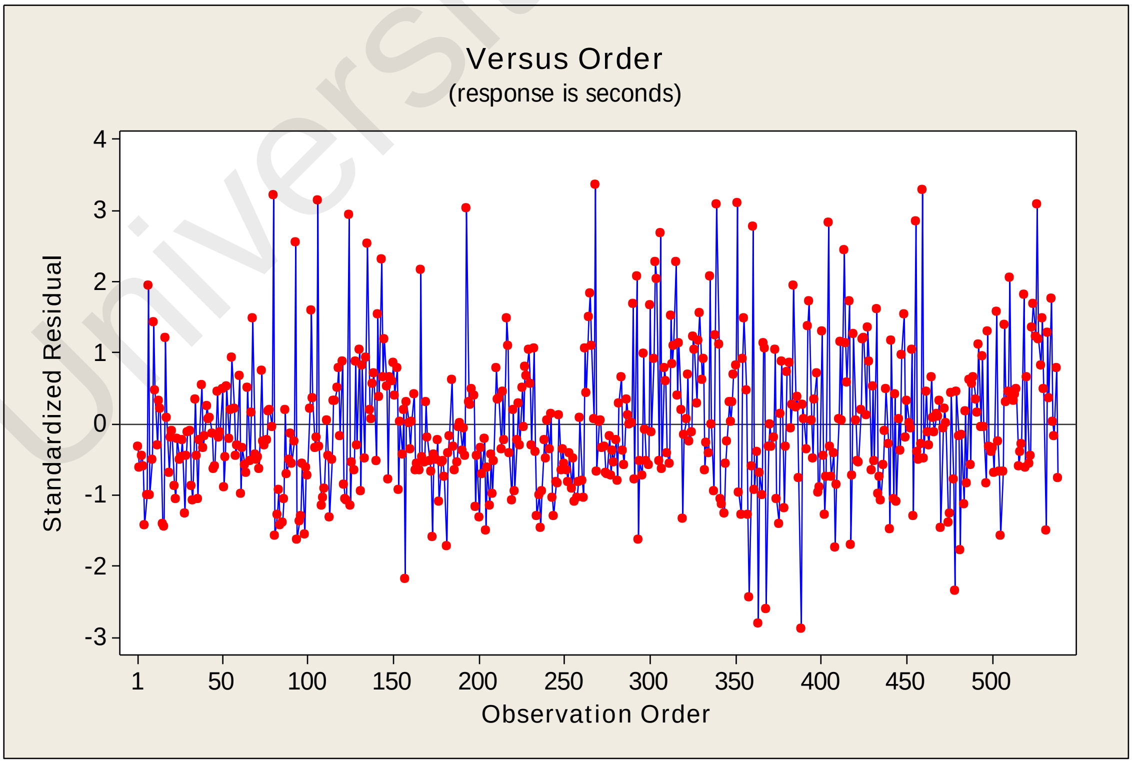

Figure 4.49: Scatterplot of observation order with standardized residual

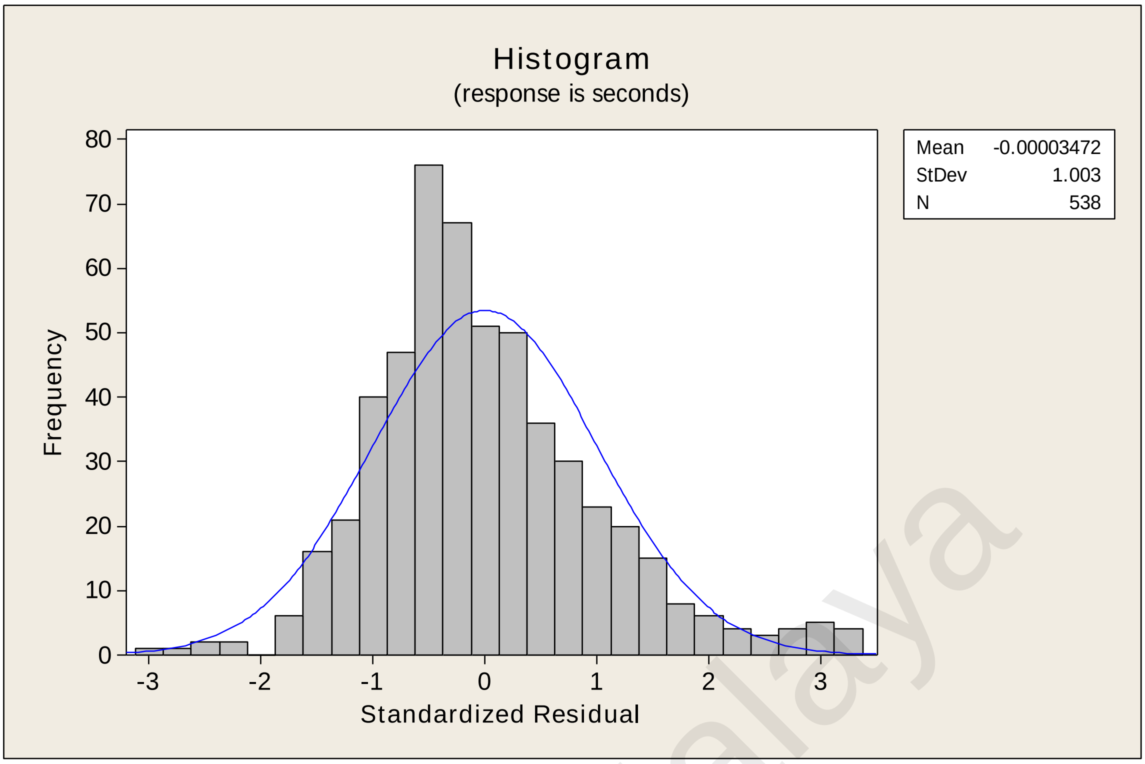

Figure 4.50: Histogram of standardized residual

Figure 4.48 shows that all the standardized residual points are within the range [-4, 4]. Figure 4.49 shows the standardized residuals have no trend and no autocorrelation effect. Figure 4.50 shows that the distribution of standardized residual is closed to normal distribution with the mean value of almost 0.

$$DWELL = \beta_1 BOARD + \beta_2 ALIGHT + \beta_3 BUS + \beta_4 TH + \beta_5 PLF + c_0 + \varepsilon \quad \textbf{4.2}$$

Table 4.12: Result of best dwell time model - Model 8

Variable	Coefficient	Standard Error	p-value	VIF
$BOARD$	0.998	0.03294	<0.001	1.195
$ALIGHT$	0.660	0.03867	<0.001	2.290
TH	12.091	1.215	<0.001	1.582
BUS	5.905	0.7946	<0.001	1.082
PLF	3.416	1.551	0.028	1.726
c_0	4.441	0.6125	<0.001	-
F-statistic	557.27	-	<0.001	-
R-squared	83.8	-	-	-

Table 4.12 shows the regression analysis result of the best dwell time model (4.2) from best subset regression analysis. Interestingly, all the dwell time effects discussed in Section 0 are statistically significant, which are transportation hub, type of bus used and the PLF. The average boarding time is 0.998 seconds per passenger while the average alighting time is 0.660 seconds per passenger. The average time for the opening and closing door operation (c_0) is 4.44 seconds. Stopping at the transportation hub increases average dwell time significantly by 12.091 seconds compared to stopping at other stations. The type of bus used also shows strong evidence of significant influence on dwell time; however, the effect is small with the one-door bus taking an average 5.905 seconds longer than a two-door bus on every stop at a bus station. Note that the PLF has statistically significant negative impact on bus dwell time, as it creates onboard friction which delays the passenger boarding and alighting processes. The coefficients of PLF shows the dwell time of a bus with full capacity ($PLF = 1$) is on average 3.416 seconds longer than the dwell time of an empty bus ($PLF = 0$). All the coefficients are statistically significant and with high R-squared value of 83.8.

The transportation hub is the interchange station with different types of public transportation and has a higher passenger flow compared to other stations. Other than that, the bus drivers also tend to wait for boarding passengers at the transportation hub. The type of bus assigned by the operator is also an important factor on dwell time. A dummy variable is used to represent the transportation hub and type of bus used in the dwell time model to differentiate the bus dwell time at the transportation hub or other stations and the effects of the two-door bus or one-door bus. The dwell time effect of passenger load on an operating bus will be discussed in detail in Section 4.3.4.

In this study, the dwell time Model 8 is more detailed with more explanatory variables compared to the general dwell time model. Table 4.11 shows that the adjusted R-squared value of Model 8 is higher than the general model (Model 1). Furthermore, the C_p value of Model 8 is 6.0, which is much lower than the C_p value of a general model at 175.9. The Model 8 with the highest R-squared value and the lowest Mallows' C_p value has a high explanatory power and is comparably more precise than the general model, in analysing the dwell time (Mallows, 1973). The residual plot of Model 8 is better than other models in terms of satisfying the assumptions and the randomness of residuals within an acceptable range.

4.3.4 Effect of Dwell Time on Different Level of Passenger Load

The result from the previous section shows that PLF is one of the factors that affect the bus dwell time. To further examine the effect of different levels of passenger load on dwell time, the regression analysis is again used to study the effect of different PLF level on bus dwell time. PLF is divided into different categories and a dwell time model is generated for each category. Since the distribution of PLF data is skewed, the data is divided into categories by using interquartile range and boxplot analysis (Wan, Wang, Liu, & Tong, 2014) to make sure each group has enough number of observations for regression analysis. After considering the skewness of the data, PLF is divided into three groups which are 0.00 to 0.25 (low), 0.25 to 0.50 (medium), and more than 0.50 (high), which have 279, 150, and 109 observations respectively. All three dwell time models are used to study the similarities and differences of the dwell time factors on each PLF level.

Multiple linear regression uses OLS estimators to predict the coefficients in the model, with assumptions such as residual of models are random, no autocorrelation, no heteroskedasticity. All these three dwell time models are full filled the assumptions of multiple linear regression as shown in Figure 4.51 to Figure 4.59.

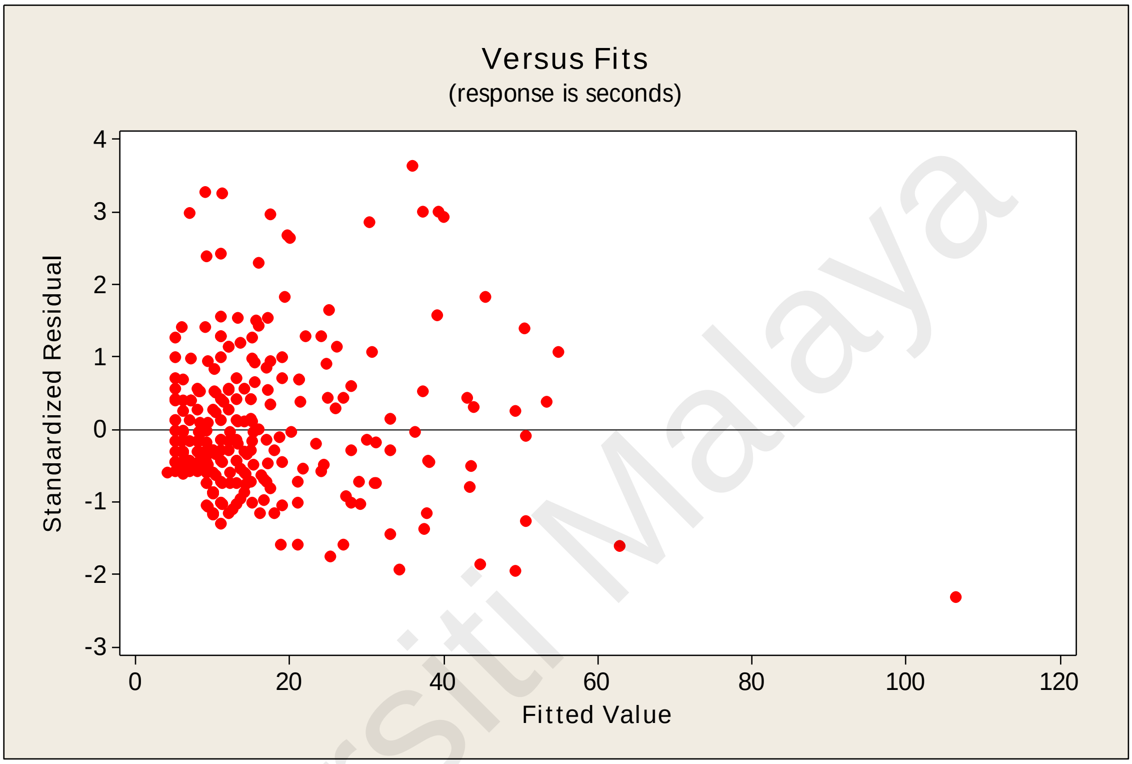

Figure 4.51: Scatterplot of fitted value vs. standardized residual (low PLF)

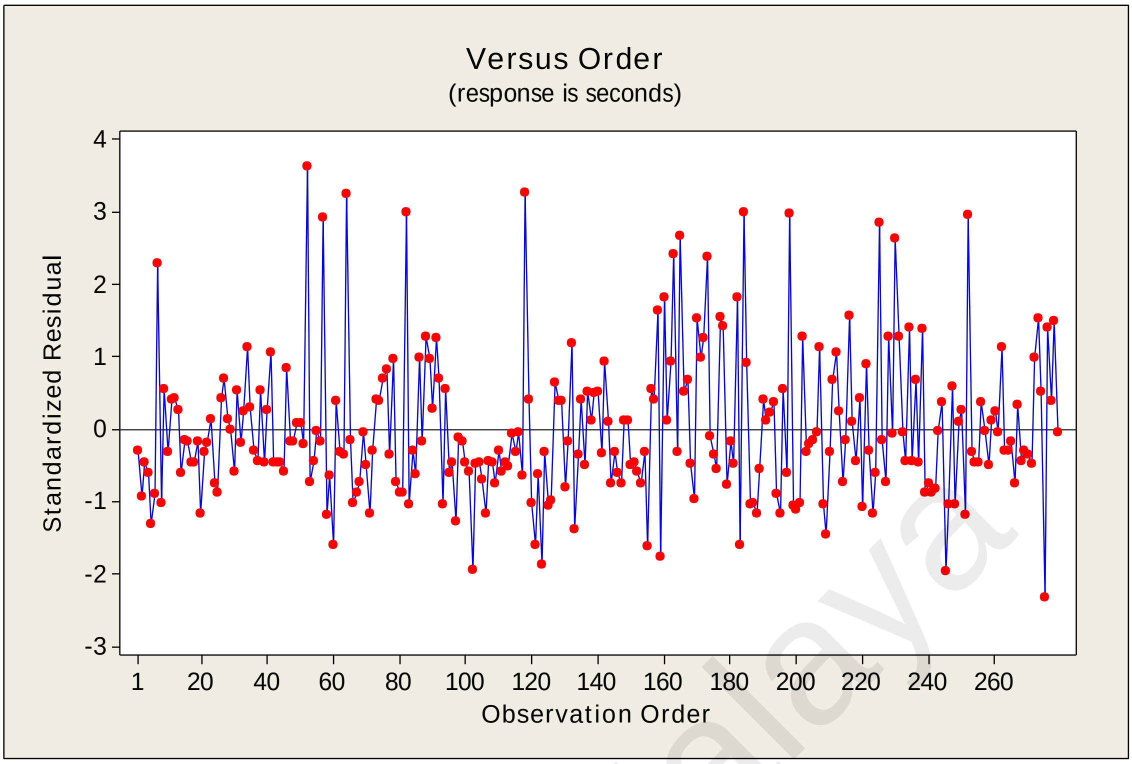

Figure 4.52: Scatterplot of observation order with standardized residual (low PLF)

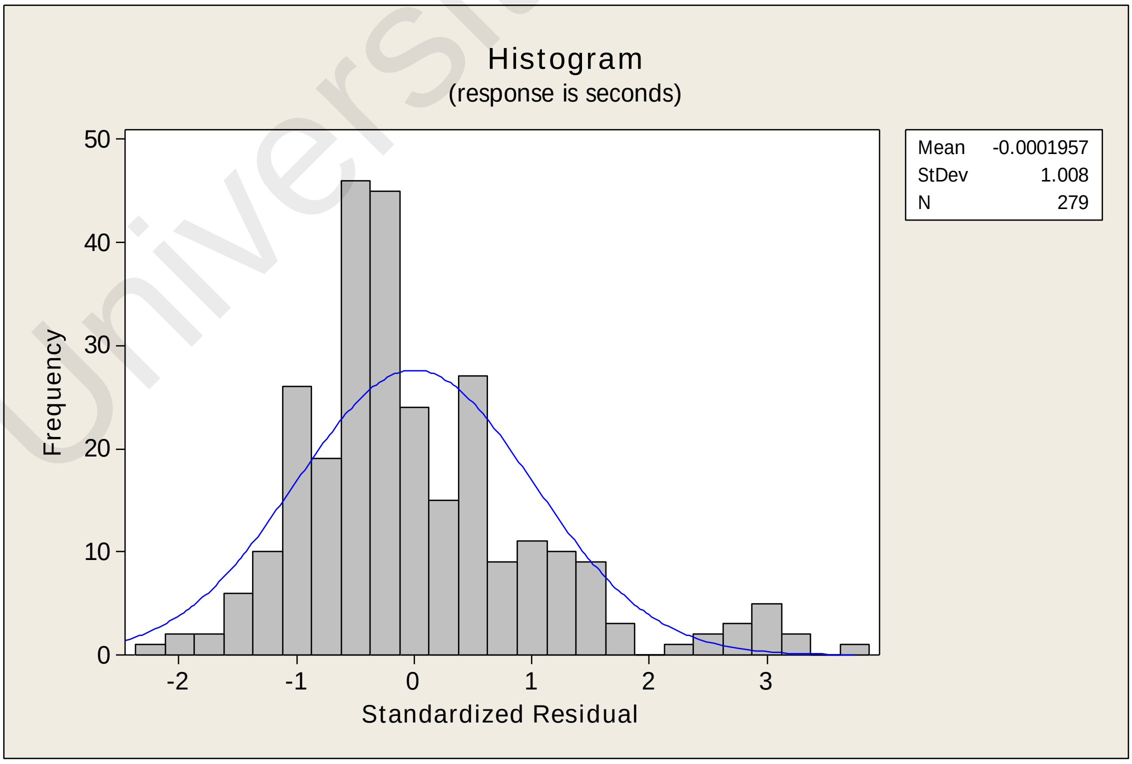

Figure 4.53: Histogram of standardized residual (low PLF)

For low PLF level, Figure 4.51 shows that all the standardized residual points are within the range [-4, 4]. Figure 4.52 shows the standardized residuals have no trend and no autocorrelation effect. Figure 4.53 shows that the distribution of standardized residual is closed to normal distribution with the mean value of almost 0.

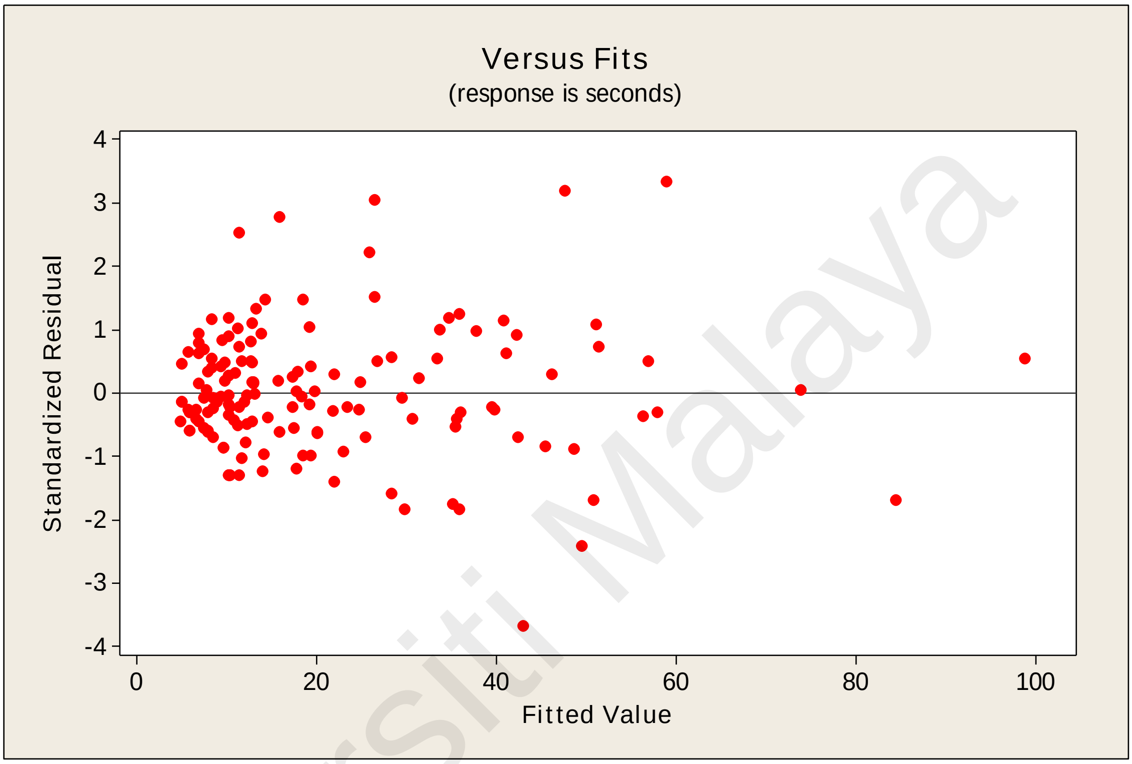

Figure 4.54: Scatterplot of fitted value vs. standardized residual (medium PLF)

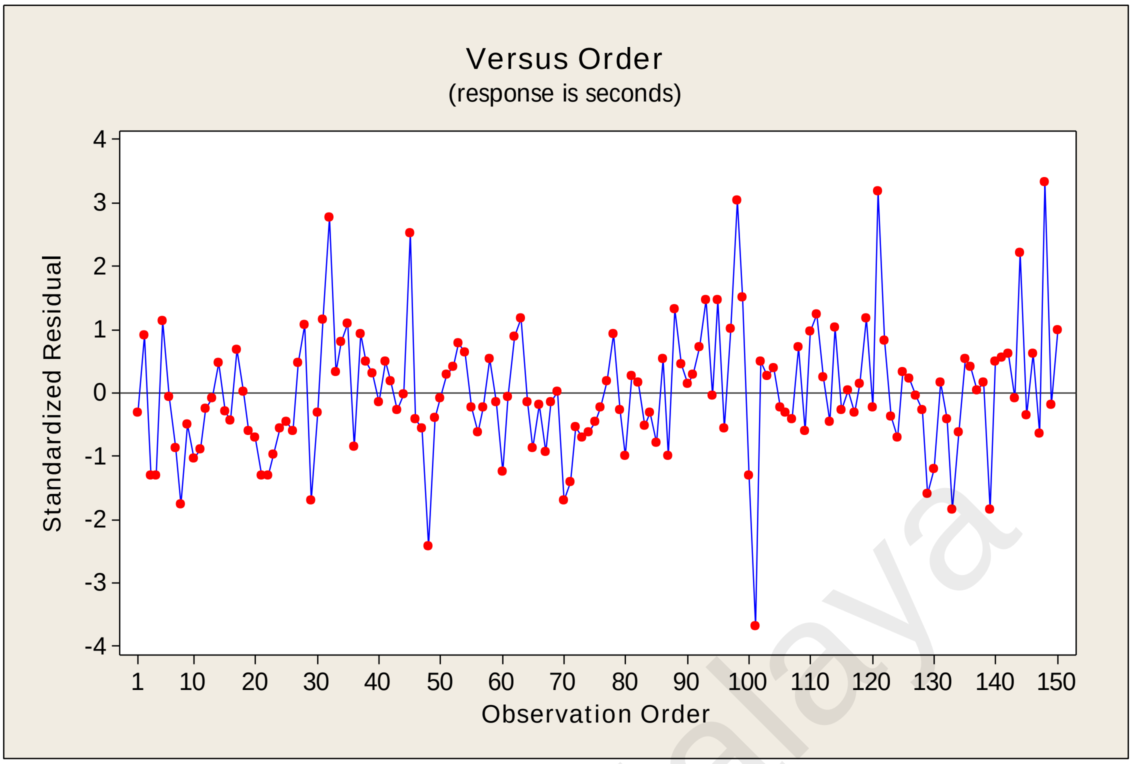

Figure 4.55: Scatterplot of observation order with standardized residual (medium PLF)

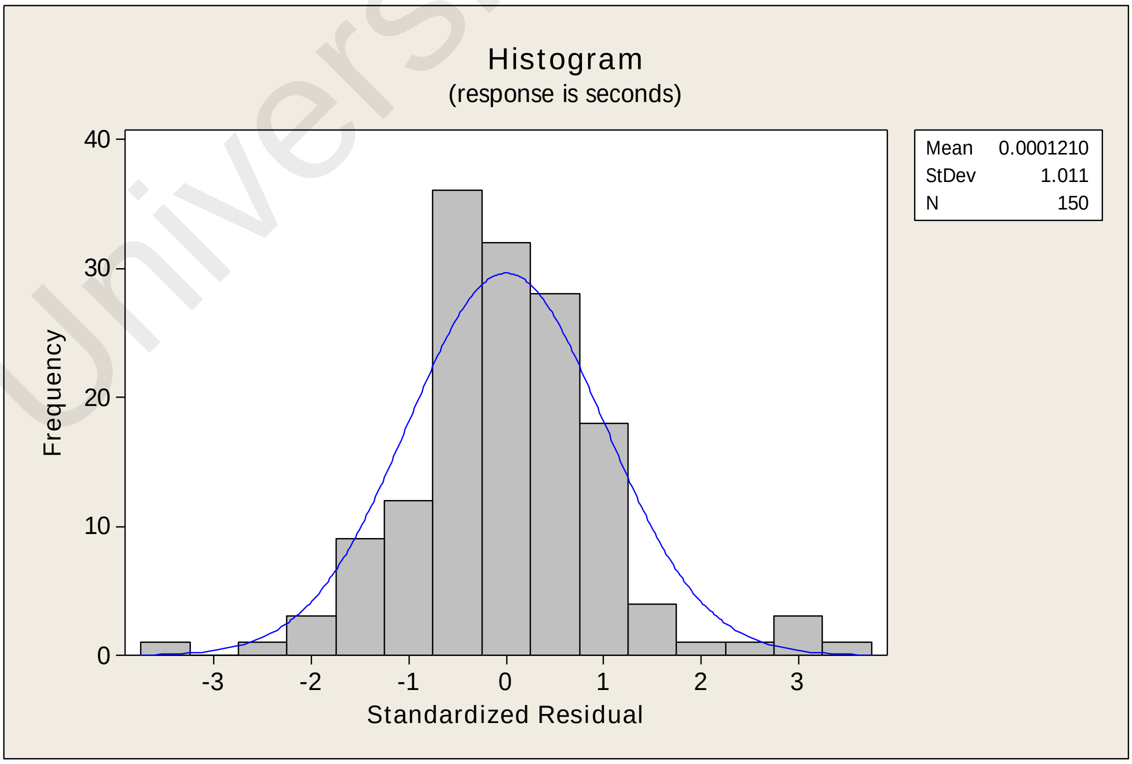

Figure 4.56: Histogram of standardized residual (medium PLF)

For medium PLF level, Figure 4.54 shows that all the standardized residual points are within the range [-4, 4]. Figure 4.55 shows the standardized residuals have no trend and no autocorrelation effect. Figure 4.56 shows that the distribution of standardized residual is closed to normal distribution with the mean value of almost 0.

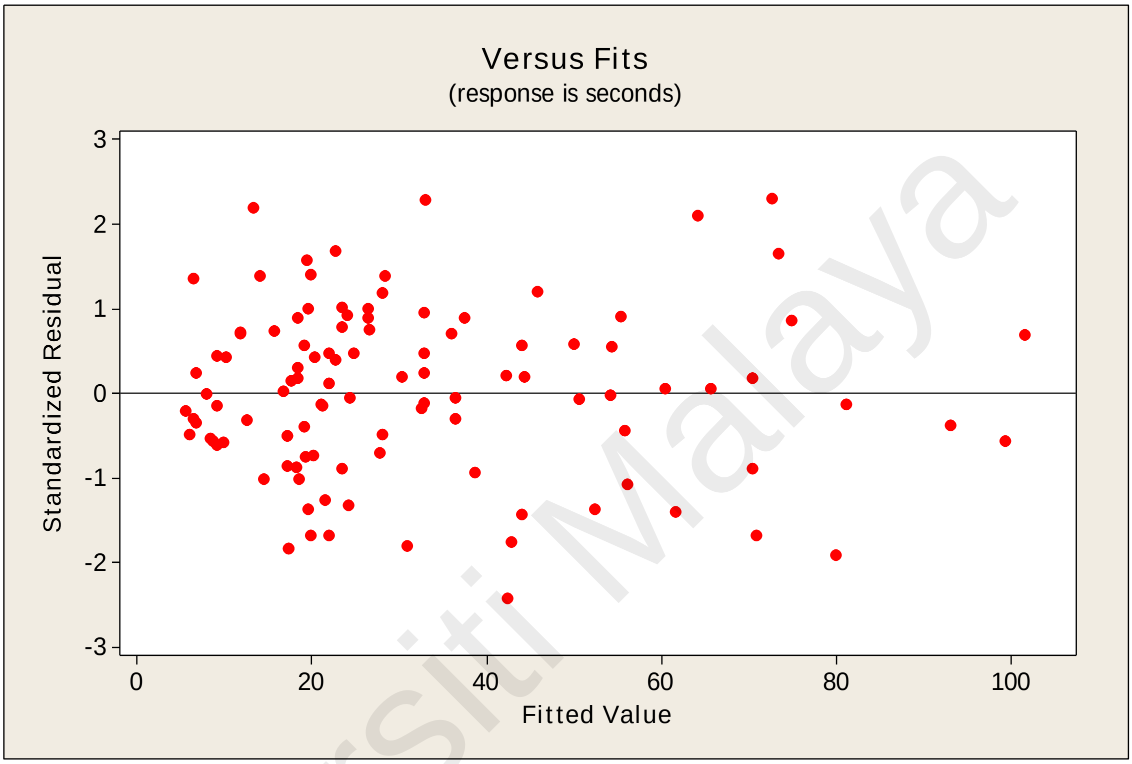

Figure 4.57: Scatterplot of fitted value vs. standardized residual (high PLF)

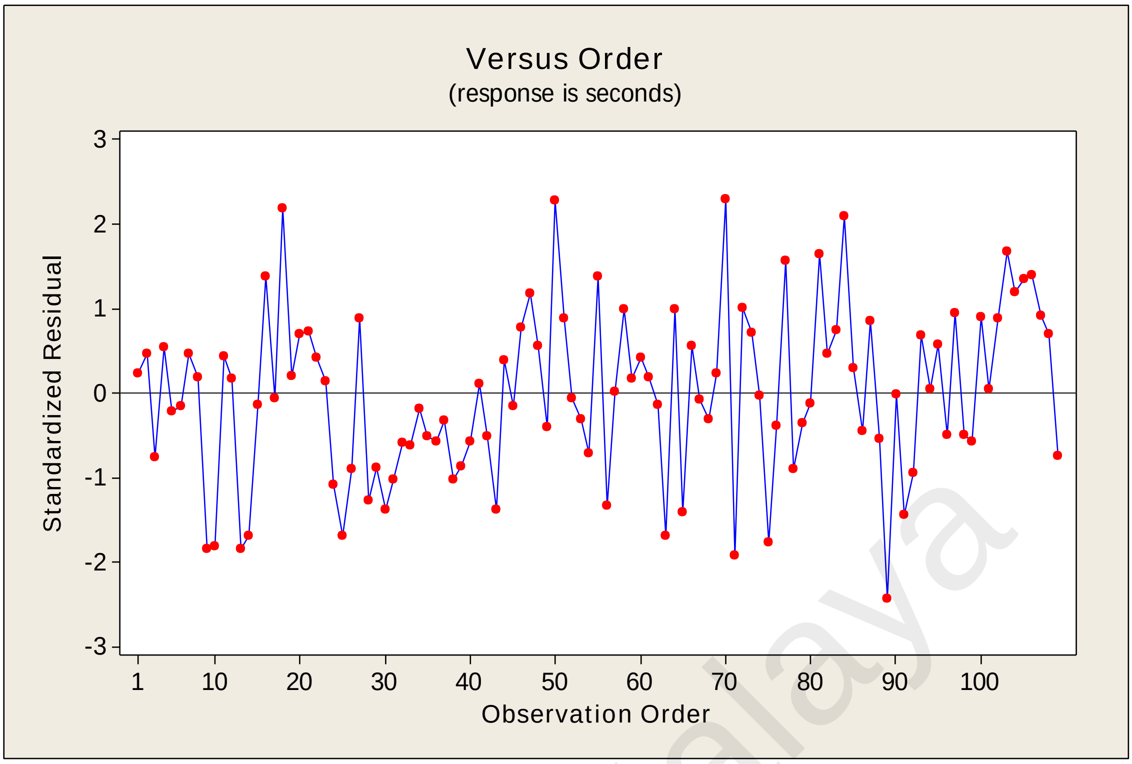

Figure 4.58: Scatterplot of observation order with standardized residual (high PLF)

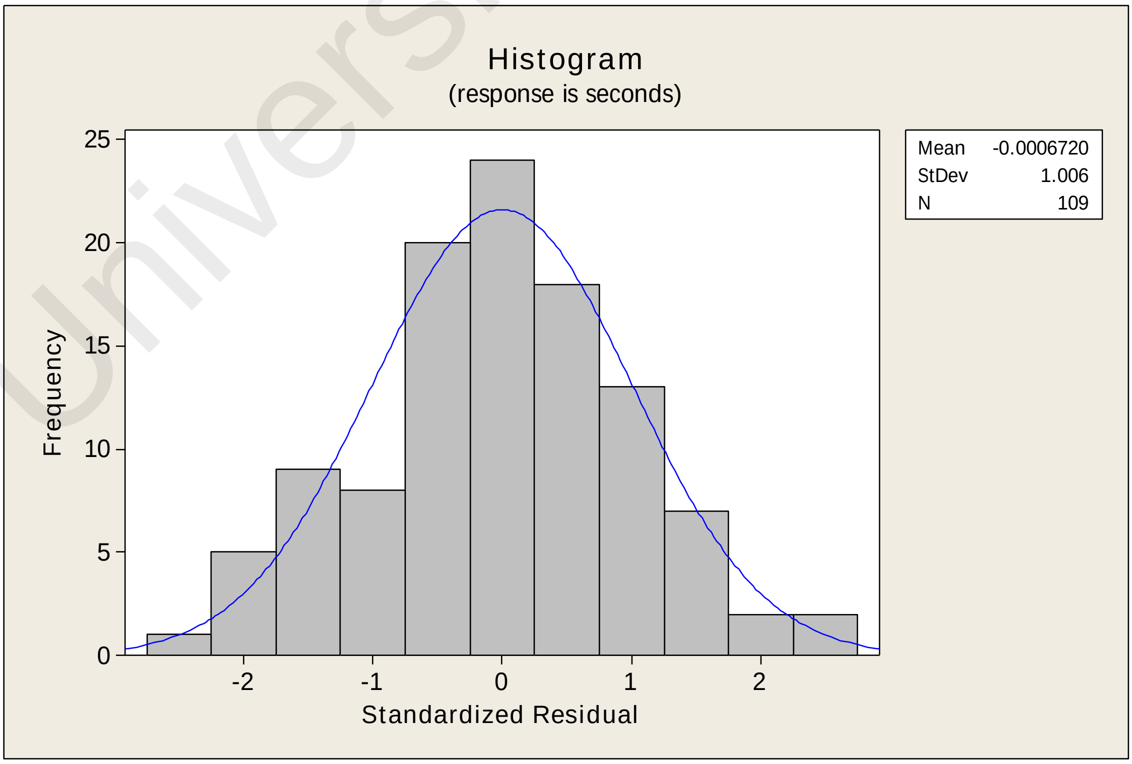

Figure 4.59: Histogram of standardized residual (high PLF)

For high PLF level, Figure 4.57 shows that all the standardized residual points are within the range [-4, 4]. Figure 4.58 shows the standardized residuals have no trend and no autocorrelation effect. Figure 4.59 shows that the distribution of standardized residual is closed to normal distribution with the mean value of almost 0.

All the models from best subset regression are tested with a margin of error at 5%. Only variables that are statistically significant, p-value less than 0.05 are included in the dwell time models. The regression coefficients of the parameters from all three dwell time models are shown in Table 4.13.

Table 4.13: Comparisons of dwell time models with different PLF levels

Variable	Coefficients		
	Low PLF	**Medium PLF**	**High PLF**
BOARD	0.996	0.999	1.166
ALIGHT	1.064	0.893	0.765
TH	11.782	12.284	-
BUS	4.966	5.393	11.227
c_0	4.156	4.010	4.978
F-statistic	219.51	238.64	239.75
n	279	150	109
R-squared	76.2	86.8	87.3
Adjusted R-squared	75.9	86.4	86.9

*All variables are 99% significant.

The number of boarding passengers and the number alighting passengers are statistically significant in all models. The average boarding time for a passenger in all three dwell time models are similar, in the range of 0.996 to 1.166 seconds. The average boarding time per passenger in the best dwell time model falls within the range too, at 0.998 seconds. The average alighting time for a passenger in all three dwell time models are similar too, in the range of 0.765 to 1.064 seconds. The average alighting time from the best dwell time model is slightly lower, which is 0.660 seconds. Furthermore, the constant term (c_0) of PLF effect models are statistically significant as well and the constant term (c_0) of the best dwell time model is within the range too. It is observed that dwell time is longer when there is higher PLF level.

The most interesting finding is that the transportation hub effect is statistically significant on the dwell time for the low and medium PLF models only. The coefficient value of transportation hub effect for the best dwell time model is within the range of both values in the model of PLF effect. Transportation hub has a different effect on dwell time at different levels of PLF. In detail, it appears that there is a strong association of transportation hub with dwell times at low and medium PLF, but no association with dwell times at high PLF. In other words, the bus dwell time has no transportation hub effect when the number of passengers in a bus is half or more than the bus passenger capacity. The bus dwell time is only affected by the transportation hub when the passenger load is less than half of the bus passenger capacity.

The onboard friction due to high passenger load in the bus is believed to have a stronger effect than the location of the bus at a transportation hub on dwell time. The delay in dwell time caused by the transportation hub effect is less significant than the high level of PLF with onboard friction in the bus. This strong onboard friction slows down the normal boarding and alighting duration of a passenger and cancels out the transportation hub effect on the bus dwell time. Moreover, the bus driver does not wait for coming passenger at the transportation hub when the bus passenger load is full, or the bus is overloaded.

Another unanticipated finding is that the bus type effect on dwell time with different PLF level is obvious and specific. This condition is observed through the dwell time models that are categorised by PLF. Table 4.13 shows that the dwell time has stronger bus type effect with high PLF level compared to low PLF level. The type of bus used for operation has an obvious and stronger effect with higher passenger load, especially during operation time with high passenger demand. In low passenger load condition, the average dwell time of a one-door bus is 3.526 seconds longer than a two-door bus. However, the average dwell time of a one-door bus is 10.540 seconds longer than a two-door bus when the passenger load of a bus is more than half of the bus passenger capacity.

The assumptions of a multiple linear regression model are satisfied for all three dwell time models, such as no regressors are highly correlated with other regressors (no multicollinearity), the error term is homoskedastic with no autocorrelation, and all regressors are uncorrelated with the error term. The adjusted R-squared, $\overline{R^2}$, and Mallows' C_p are used to compare the goodness-of-fit among dwell time models. The model with higher $\overline{R^2}$ value has better explanatory power on dwell time, whereas for Mallows' C_p, the lower the value and the closer to the number of independent variables plus the constant, the stronger the explanatory power of dwell time model (Mallows, 1973).

4.3.5 Discussion

Bus dwell time models are presented by using multiple linear regression and the factors that affect the dwell time are statistically proven. The error term of all regression models are independently and identically normally distributed with zero mean and constant variance. All assumptions are held with no significant multicollinearity and heterogeneous effect.

The average boarding time of a passenger for the general model and Model 8 are similar with insignificant difference, only 0.06 seconds. The average passenger alighting time in Model 8 is slightly lower than the general model, about 0.16 seconds per passenger only. Furthermore, the constant term (c_0) of Model 8 is significantly lower than the constant term (c_0) of the general dwell time model. The best dwell time model (Model 8) has lower value of the constant term due to the additional variables in the model, which are transportation hub, type of bus used and PLF.

Dwell time presents better on the Model 8, with more factors explaining the effects of dwell time, than the general model, with number of boarding and alighting passengers only. Some effects of dwell time in the general model are hidden due to the lack of an independent variable in the model which causes a lower adjusted R-squared value than Model 8. Other than the number of boarding and alighting passengers, the effects of transportation hub, bus type used and PLF on dwell time are significant. The two-door bus takes lesser time than the one-door bus to serve the same amount of boarding and alighting passengers. The bus also spends longer dwell time at the transportation hub compared to other bus stations.

Since the passenger capacity of bus is different, the PLF is used as a standard indicator to measure the onboard crowdedness in an operating bus. It is demonstrated that the dwell time is affected by the level of onboard crowdedness in the bus. Dwell time models with PLF effects explain the dwell time more appropriately than the general model with specific passenger load condition of a bus. The adjusted R-squared values of all three models with PLF effects are considered high, between 75.9 and 87.3. Dwell time models with different PLF levels have a high explanatory power on dwell time and the effects of PLF on the bus dwell time is statistically significant. Dwell time models with different levels of PLF show the findings in more details compared to the best dwell time model (Model 8) from Section 4.3.3. The best dwell time model from the previous section is suitable for dwell time study which involves a wide range of PLF values, whereas dwell time models on different PLF levels show a more significant study on dwell time in certain categories of PLF.

During peak hour with high passenger demand, which has high PLF level, the dwell time of a bus is only affected by the type of bus used, and the number of boarding and alighting passengers. The transportation hub does not affect the bus dwell time when a bus has high PLF level or during peak hour period. The bus tends to stop longer when there is a low PLF level in the bus to wait for any extra passenger to board the bus and this brings a different effect for different PLF values. The result of this analysis shows that the dwell time with a high PLF level bus is purely affected by the type of bus used, and the number of boarding and alighting passengers only. Hence, the selection of bus type used for operation is crucial especially when a bus has high PLF level and during peak hour period with high passenger demand.

4.4 Bus Timetable Optimisation

The person capacity with high ability to cater to the passenger demand is key for a good quality bus service. The study from Section 4.2 and 4.3 shows that bus dwell time is affected by the passenger demand indirectly. Dwell time is a crucial parameter that influences the transit speed and reliability. The focus of this section is to propose an optimal bus timetable by using simulation of bus timetable optimisation based on passenger demand.

One of the objectives of bus timetable optimisation is to minimise the total dwell time. The dwell time model is used to calculate the bus dwell times at all stations in the bus timetable optimisation with considerations given to dwell time factors, such as number of passengers boarding and alighting, station type, bus type used and PLF. By reducing the dwell time, the overall trip time is reduced, and the transit speed is improved. Another objective of this optimisation is to minimise the passenger waiting time at the bus station. At the same time, the passenger load is also controlled so that it does not exceed the maximum passenger capacity of a bus. The satisfaction of passengers can be increased by improving the onboard condition of a bus and by reducing the waiting time at the bus station.

The optimal bus timetable generated by the simulation optimisation is compared with the current timetable to verify the potential of the proposed bus timetable. In order to compare the performance of the timetable, depending on passenger ridership, against the timetable that is currently used, the deviation ratios of the total dwell time and the total waiting time are calculated by

$$\frac{Optimal\ time - Current\ time}{Current\ time} \times 100\%. \qquad \mathbf{4.3}$$

4.4.1 Bus Route A

The current and optimal bus timetable for Bus Route A are presented in Table 4.14 and Table 4.15 respectively. In both tables, 2-door bus is represented by "0" and 1-door bus is represented by "1".

Table 4.14: Current bus timetable for Bus Route A

Trip	Departure Time	Bus Type	Trip	Departure Time	Bus Type	Trip	Departure Time	Bus Type
1	8:00am	0	19	12:00pm	0	37	4:00pm	0
2	8:10am	1	20	12:10pm	1	38	4:10pm	1
3	8:20am	0	21	12:20pm	0	39	4:20pm	0
4	8:30am	1	22	12:30pm	1	40	4:30pm	1
5	8:40am	0	23	12:40pm	0	41	4:40pm	0
6	8:50am	1	24	12:50pm	1	42	4:50pm	1
7	9:00am	0	25	1:00pm	0	43	5:00pm	0
8	9:10am	1	26	1:10pm	1	44	5:10pm	1
9	9:20am	0	27	1:20pm	0	45	5:20pm	0
10	9:30am	1	28	1:30pm	1	46	5:30pm	1
11	9:40am	0	29	1:40pm	0	47	5:40pm	0
12	9:50am	1	30	1:50pm	1	48	5:50pm	1
13	10:00am	0	31	2:00pm	0	49	6:00pm	0
14	10:20am	0	32	2:20pm	0	50	6:10pm	1
15	10:40am	0	33	2:40pm	0	51	6:20pm	0
16	11:00am	0	34	3:00pm	0	52	6:30pm	1
17	11:20am	0	35	3:20pm	0	53	6:40pm	0
18	11:40am	0	36	3:40pm	0	54	6:50pm	1

Table 4.15: Optimal bus timetable for Bus Route A

Trip	Departure Time	Bus Type	Trip	Departure Time	Bus Type	Trip	Departure Time	Bus Type
1	8:00a.m.	0	19	11:10a.m.	0	37	3:30p.m.	0
2	8:10a.m.	1	20	11:20a.m.	0	38	3:50p.m.	0
3	8:20a.m.	0	21	11:40a.m.	0	39	4:00p.m.	0
4	8:39a.m.	0	22	11:49a.m.	0	40	4:10p.m.	0
5	8:46a.m.	0	23	12:02p.m.	0	41	4:20p.m.	0
6	8:50a.m.	0	24	12:20p.m.	0	42	4:30p.m.	0
7	8:53a.m.	0	25	12:50p.m.	0	43	4:39p.m.	0
8	9:00a.m.	1	26	1:05p.m.	0	44	4:48p.m.	0
9	9:20a.m.	0	27	1:32p.m.	0	45	5:00p.m.	1
10	9:37a.m.	0	28	1:40p.m.	0	46	5:06p.m.	0
11	9:46a.m.	0	29	1:46p.m.	0	47	5:15p.m.	0
12	9:52a.m.	0	30	2:00p.m.	0	48	5:24p.m.	0
13	10:06a.m.	0	31	2:06p.m.	1	49	5:33p.m.	1
14	10:17a.m.	1	32	2:20p.m.	0	50	6:06p.m.	0
15	10:28a.m.	0	33	2:30p.m.	0	51	6:16p.m.	0
16	10:40a.m.	1	34	2:50p.m.	0	52	6:26p.m.	0
17	10:50a.m.	0	35	3:00p.m.	0	53	6:46p.m.	0
18	11:02a.m.	0	36	3:20p.m.	0			

In the current timetable, the total dwell time for all trips along the bus route is 156.91 minutes and the total waiting time for all passengers at all stops is 45790 minutes. The number of bus trips for proposed timetable is reduced to 53 trips, one trip lesser than current bus timetable. The total dwell time and the total waiting time of the proposed demand-based timetable and the currently used timetable are compared. The comparative results are shown in Table 4.16.

Table 4.16: Comparative results on both timetables

Situation	Number of trips	Total dwell time (min)	Average dwell time (min)	Total waiting time (min)	Deviation ratio	
					Average dwell time (%)	Total waiting time (%)
Current timetable	54	156.91	2.91	45790	-11.35	-18.93
Proposed timetable	53	136.72	2.58	37122		

The result shows that the optimal passenger demand-based timetable has shortened the average dwell time by 11.35% compared to the current bus timetable. The proposed timetable also reduces the total passenger waiting time by 18.93% from the current bus timetable. The average dwell time and the total passenger waiting time of the passenger demand-based timetable are significantly shorter than the current bus timetable.

4.4.1.1 Person capacity of Bus Route A

Person capacity of the bus timetable is analysed by using the number of buses assigned and the bus type used in every hour on the timetable. Table 4.17 shows the comparison between the current timetable and the proposed timetable in terms of the number of bus trips employed in every hour.

Table 4.17: Number of bus trips on current and proposed timetables of Bus Route A

Time Interval	Ridership (%)	Number of bus trips	
		Current	Proposed
8:00-9:00a.m.	14	6	7
9:00-10:00a.m.	9	6	5
10:00-11:00a.m.	8	3	5
11:00a.m.-12:00p.m.	10	3	5
12:00-1:00p.m.	6	6	3
1:00-2:00p.m.	8	6	4
2:00-3:00p.m.	9	3	5
3:00-4:00p.m.	8	3	4
4:00-5:00p.m.	12	6	6
5:00-6:00p.m.	8	6	5
6:00-7:00p.m.	8	6	4

For 12:00p.m. to 1:00p.m., which has 6% of total ridership, the number of bus trips in the proposed timetable has been reduced to three. For 8:00a.m. to 9:00a.m., with 14% of total ridership (the highest hourly ridership), seven bus trips are proposed. Number of bus trips for the time intervals of 10:00a.m. to 11:00a.m., 11:00a.m. to 12:00p.m., and 2:00p.m. to 3:00p.m. has increased from three to five bus trips. Some peak hours from the current bus timetable are assigned with lesser bus trips on proposed timetable, which are during the periods of 9:00a.m. to 10:00a.m., 5:00p.m. to 6:00p.m., and 6:00p.m. to 7:00p.m.

The proposed timetable is analysed on the congruity of passenger demand. The analysis result of Bus Route A in terms of person capacity is summarised in Table 4.18. Table 4.18 shows that the person capacity of the proposed bus timetable match with the passenger demand.

Table 4.18: Person capacity of current and proposed timetables on Bus Route A

Time Interval	Ridership (%)	Person Capacity	
		Current Timetable	Proposed Timetable
8:00-9:00a.m.	14	309	418
9:00-10:00a.m.	9	309	292
10:00-11:00a.m.	8	189	269
11:00a.m.-12:00p.m.	10	189	315
12:00-1:00p.m.	6	309	189
1:00-2:00p.m.	8	309	252
2:00-3:00p.m.	9	189	292
3:00-4:00p.m.	8	189	252
4:00-5:00p.m.	12	309	378
5:00-6:00p.m.	8	309	269
6:00-7:00p.m.	8	309	252

4.4.1.2 Analysis on bus timetable of Bus Route A

The number of bus trips for proposed timetable reduced to 53 trips, one trip lesser than the current timetable, yet the passenger waiting time and dwell time are reduced. In the proposed timetable, the person capacity during 8:00a.m. to 9:00a.m., 11:00a.m. to 12:00p.m., and 4:00p.m. to 5:00p.m. are higher than the current timetable. The person capacity of current timetable is not enough to cope with the current passenger demand. For noon peak hours (12:00p.m. to 2:00p.m.), the person capacity of proposed timetable is reduced due to low ridership compared to other time intervals. The reduced in passenger waiting time on proposed timetable due to sufficient buses and bus departure times are assigned according to the passenger demand distribution.

4.4.2 Bus Route B

The current and optimal bus timetable for Bus Route B are shown in Table 4.19 and Table 4.20 respectively. In both tables, 2-door bus is represented by “0” and 1-door bus is represented by “1”.

Table 4.19: Current bus timetable for Bus Route B

Trip	Departure Time	Bus Type	Trip	Departure Time	Bus Type	Trip	Departure Time	Bus Type
1	8:00am	0	19	12:00pm	0	37	4:00pm	0
2	8:10am	1	20	12:10pm	1	38	4:10pm	1
3	8:20am	0	21	12:20pm	0	39	4:20pm	0
4	8:30am	1	22	12:30pm	1	40	4:30pm	1
5	8:40am	0	23	12:40pm	0	41	4:40pm	0
6	8:50am	1	24	12:50pm	1	42	4:50pm	1
7	9:00am	0	25	1:00pm	0	43	5:00pm	0
8	9:10am	1	26	1:10pm	1	44	5:10pm	1
9	9:20am	0	27	1:20pm	0	45	5:20pm	0
10	9:30am	1	28	1:30pm	1	46	5:30pm	1
11	9:40am	0	29	1:40pm	0	47	5:40pm	0
12	9:50am	1	30	1:50pm	1	48	5:50pm	1
13	10:00am	0	31	2:00pm	0	49	6:00pm	0
14	10:20am	0	32	2:20pm	0	50	6:10pm	1
15	10:40am	0	33	2:40pm	0	51	6:20pm	0
16	11:00am	0	34	3:00pm	0	52	6:30pm	1
17	11:20am	0	35	3:20pm	0	53	6:40pm	0
18	11:40am	0	36	3:40pm	0	54	6:50pm	1

Table 4.20: Optimal bus timetable for Bus Route B

Trip	Departure Time	Bus Type	Trip	Departure Time	Bus Type	Trip	Departure Time	Bus Type
1	8:00a.m.	0	23	11:21a.m.	0	45	3:38p.m.	0
2	8:12a.m.	1	24	11:35a.m.	1	46	3:50p.m.	0
3	8:20a.m.	0	25	11:45a.m.	0	47	4:00p.m.	0
4	8:27a.m.	1	26	12:05p.m.	0	48	4:10p.m.	0
5	8:35a.m.	0	27	12:15p.m.	1	49	4:20p.m.	0
6	8:40a.m.	0	28	12:30p.m.	0	50	4:31p.m.	0
7	8:46a.m.	0	29	12:40 p.m.	0	51	4:35p.m.	1
8	8:52a.m.	0	30	12:50 p.m.	0	52	4:41p.m.	0
9	9:00a.m.	0	31	1:05p.m.	1	53	4:45p.m.	1
10	9:09a.m.	0	32	1:13p.m.	0	54	4:50p.m.	0
11	9:20a.m.	0	33	1:20p.m.	1	55	4:56p.m.	0
12	9:32a.m.	1	34	1:28p.m.	0	56	5:00p.m.	0
13	9:40a.m.	0	35	1:45p.m.	0	57	5:10p.m.	1
14	9:50a.m.	0	36	1:52p.m.	0	58	5:20p.m.	0
15	9:56a.m.	1	37	2:05p.m.	0	59	5:27p.m.	0
16	10:06a.m.	0	38	2:20p.m.	0	60	5:40p.m.	0
17	10:15a.m.	0	39	2:32p.m.	0	61	5:51p.m.	0
18	10:25a.m.	0	40	2:46p.m.	0	62	6:03p.m.	0
19	10:45a.m.	0	41	2:59p.m.	1	63	6:11p.m.	0
20	10:50a.m.	0	42	3:06p.m.	0	64	6:26p.m.	0
21	11:00a.m.	0	43	3:20p.m.	0	65	6:43p.m.	0
22	11:07a.m.	1	44	3:26p.m.	0	66	6:45p.m.	0

In the currently used timetable, the total dwell time for all trips along the bus route is 87.17 minutes and the total waiting time for all passengers at all stops is 25439 minutes. The number of bus trips for proposed timetable increased to 66 trips. The total dwell time and the total waiting time of the proposed demand-based timetable and the current timetable are compared. The comparative results are shown in Table 4.21.

Table 4.21: Comparative results in both timetables

Situation	Number of trips	Total dwell time (min)	Average dwell time (min)	Total waiting time (min)	Deviation ratio	
					Average dwell time (%)	Total waiting time (%)
Current timetable	54	87.17	1.61	25439	-9.48	-20.15
Proposed timetable	66	96.19	1.46	20312		

The result in Table 4.21 shows that the optimal passenger demand-based timetable has shortened the average dwell time by 9.48% compared to the current bus timetable. The proposed timetable also reduced the total passenger waiting time by 20.15% from the current bus timetable. The average dwell time and the total passenger waiting time of the passenger demand-based timetable are significantly shorter than the current bus timetable.

4.4.2.1 Person capacity of Bus Route B

Person capacity of the bus timetable is analysed by using the number of buses assigned and the bus type used in every hour on the timetable. Table 4.22 shows the comparison between the current timetable and the proposed timetable in terms of the number of bus trips employed in every hour.

Table 4.22: Number of bus trips on current and proposed bus timetables of Bus Route B

Time Interval	Ridership (%)	Number of bus trips	
		Current	Proposed
8:00-9:00a.m.	12	6	8
9:00-10:00a.m.	11	6	7
10:00-11:00a.m.	8	3	5
11:00a.m.-12:00p.m.	7	3	5
12:00-1:00p.m.	7	6	5
1:00-2:00p.m.	9	6	6
2:00-3:00p.m.	7	3	5
3:00-4:00p.m.	8	3	5
4:00-5:00p.m.	14	6	9
5:00-6:00p.m.	9	6	6
6:00-7:00p.m.	8	6	5

Note that the number of bus trips for peak hour periods 8:00a.m. to 9:00a.m., 9:00a.m. to 10a.m., and 4:00p.m. to 5:00p.m. are increased from original six trips to eight, seven, and nine trips respectively. Besides, the minimum number of bus trips per hour has increased to five trips. The increment of number of bus trips throughout all time periods show that the current passenger capacity is not enough to cater the passenger demand. During 12:00p.m. to 1:00p.m. and 6:00p.m. to 7:00p.m., the number of bus trips are reduced from six trips to five trips to improve the overall bus timetable efficiency. The proposed timetable is analysed on the congruity of passenger demand. The analysis result of Bus Route B in terms of person capacity is optimization in Table 4.23.

Table 4.23: Person capacity of current and proposed timetable of Bus Route B

Time Interval	Ridership (%)	Person Capacity	
		Current Timetable	Proposed Timetable
8:00-9:00a.m.	12	309	458
9:00-10:00a.m.	11	309	395
10:00-11:00a.m.	8	189	315
11:00a.m.-12:00p.m.	7	189	269
12:00-1:00p.m.	7	309	292
1:00-2:00p.m.	9	309	332
2:00-3:00p.m.	7	189	292
3:00-4:00p.m.	8	189	315
4:00-5:00p.m.	14	309	521
5:00-6:00p.m.	9	309	355
6:00-7:00p.m.	8	309	315

4.4.2.2 Analysis on bus timetable of Bus Route B

The reduced in passenger waiting time on proposed timetable due to sufficient buses and bus departure times are assigned according to the passenger demand distribution. Besides, the number of bus trips for proposed timetable increased to 66 trips, due to high number of passenger demand. The daily ridership for Bus Route B is much higher than Bus Route A. Hence, the bus trips for proposed timetable of Bus Route B is much higher than the current timetable. This situation shows that different bus routes has different passenger demand distribution. The number of bus trips for each bus route should assigned according to the specific passenger demand distribution.

4.4.3 Discussion

One of the most significant findings from this study is that the current bus timetable is not optimised whereby the person capacity does not suit the passenger demand distribution. The misallocation of the bus trip departure time in the timetable causes resources wastage and low satisfaction level from passengers. For example, extra buses are assigned when passenger ridership is low and yet, there are insufficient buses dispatched during high passenger demand period. Besides, the occurrence of onboard overloading happens during peak hours, which indicates that the current person capacity is scarce. Furthermore, it is important for this research to identify the parameters that can measure the performance competency of the campus bus service. Dwell time and passenger waiting time are the parameters that can measure performance competency of the campus bus service.

The person capacity in the proposed timetable is sufficient to cater to the passenger ridership. Besides, the departure times of the bus trip is assigned according to the passenger demand distribution in the proposed timetable. Hence, the situation of bus overload does not occur. The passenger load in the bus for all departures does not exceed the maximum capacity, and passenger waiting time is reduced at the same time.

With the current situation, it is necessary to assign number of bus trips depends on the passenger demand to handle the passenger ridership on the campus bus service with sufficient person capacity. The optimisation of bus timetable overcomes the bus oversupply or undersupply problems, which involve the decision on bus type used and the assignment of bus trip departure times. The situation of inefficient bus trips allocation is overcome by the proposed demand-based bus timetable.

4.5 Summary of Results and Discussions

The responses from the questionnaire survey on the bus transit performance are different for both bus routes. Therefore, the transit performance aspect of every bus route has to be studied separately for an integrated solution to improve the overall bus transit performance. One of the significant findings that emerged from this questionnaire survey is that the implementation of an improved bus timetable can encourage students to shift their transportation mode from private vehicle to the campus bus, especially among car owners. 73% of the respondents who are car owner are willing to change their transportation mode to the campus bus if the bus timetable is improved. The university's authority should not overlook the importance of an efficient bus service management. Any discontent in the performance measures should be redressed as the issues are accumulable and may result in poor assessment. The passenger demand should be given consideration so that a high performance and efficient on-campus bus service can be established.

One of the most significant findings to have emerged from the passenger demand and person capacity analysis is that the current peak hour interval with high person capacity does not suit the passenger demand distribution. The current bus timetable is not optimised. This misallocation of bus departure times on timetable causes resources wastage and low satisfaction level from the passengers. For example, extra buses are assigned during the off-peak hour with low passenger ridership and yet, insufficient buses are dispatched during peak passenger demand. Besides, the occurrence of overloading onboard happens during peak hours, which indicate that the current person capacity is scarce.

With the current situation, it is necessary to redefine the peak hours to ensure that there is higher person capacity for those periods compared to during the off-peak hour to better handle the passenger ridership on the campus bus service. The optimisation of person capacity which involves the decision on the type of bus used and the assignment of bus departure timetable should be focused on to avoid the situation of oversupply or undersupply of buses.

These findings enhance the justification of the outcomes from the questionnaire survey analysis, whereby most of the respondents had recommended to increase the number of operating buses, especially during peak passenger demand periods. With regards to this situation, a revised demand-based operation timetable is exceedingly needed to redress the inadequacy of the bus resources allocation.

Dwell time model analysis demonstrates the importance of implementing the adequate infrastructure into the public bus system, especially on the bus type used during high passenger ridership. During peak hour period with high passenger ridership, the two-door bus with higher passenger capacity is more efficient than the one-door bus in serving passengers. The efficiency in terms of time should be one of the most important considerations for public bus system evaluation, such as passenger waiting time at bus station and bus dwell time.

The bus timetable optimisation proposes a demand-based timetable where the average dwell time and total passenger waiting time are reduced, which is good for the bus operator and passengers. Generally, both the average dwell time and the total passenger waiting time of the optimal bus timetable are shorter than those in the current timetable. In the optimal timetable, the dwell time at all bus stations are generated from the regression model and used in the timetable optimisation model. For Bus Route A, the current bus timetable has high departing frequency during non-peak hours compared to the proposed bus timetable. By using the proposed timetable that is generated based on passenger demand distribution, the dwell time and waiting time are reduced.

The result clearly shows the importance of the assignment of bus trip departure time according to the passenger demand distribution. By using the bus timetable optimisation model, the efficiency and robustness of the bus timetable are improved. Misassignment of the bus trip departure time will result in wasted resources or displeased outcomes which reduces the bus performance, especially the transit speed and reliability. A non-optimal timetable not only reduces the congruity between passenger demand and person capacity, it also increases the passenger waiting time for a bus arrival. By establishing the bus timetable according to the passenger ridership distribution, the optimisation of bus timetable assigns the person capacity that adheres to the passenger demand, thereby reducing operating expenses, resources and manpower.

CHAPTER 5: CONCLUSION

5.1 Overview of Research Work

In this study, the first objective was to identify the satisfactory level of bus passengers on the performance of the campus bus service and to provide recommendations based on the survey outcomes. The objective was achieved by distributing questionnaires among students to collect their opinions on the current bus service performance. The second objective was to evaluate the effectiveness of the bus service by using passenger load factor. This objective was achieved by studying the passenger demand distribution and the person capacity of the bus timetable. The average passenger load factor (PLF) is calculated by using passenger demand and person capacity of every bus trip. The third objective was to determine the factors of bus dwell time with the multiple linear regression model. The factors that affect bus dwell time were identified by using the best subset regression analysis. The effect of dwell time on different PLF levels were also analysed using the dwell time model generated by multiple regression analysis. The last objective was to generate a demand-based bus timetable that is based on timetable optimisation by minimising dwell time and passenger waiting time in order to develop an effective and efficient sustainable transit bus system in University of Malaya (UM) Campus. An optimal bus timetable was proposed by using the simulation of bus timetable optimisation whereby the dwell time and passenger waiting time are minimised. Genetic algorithm (GA) is used to solve the timetable optimisation problem. An optimal bus timetable was generated with the bus trip departure time and bus type used.

5.1.1 Satisfaction Level of Bus Passenger

The passenger perception of the current campus bus service was surveyed and analysed. The descriptive analysis such as mode, median, and mean was used to identify the satisfaction level of passengers and the shortcomings of the transit bus service, depending on the distribution of the questionnaire data.

Less than half of the respondents were satisfied with the current bus service. The overall performance of both bus routes were within acceptable range, but had some flaws such as the crowdedness condition in the bus. The number of bus trips assigned is insufficient to cater to the passenger ridership, especially during peak hours. The situation of undersupply of person capacity is more serious on Bus Route B than Bus Route A. Most of the respondents suggested that the current bus timetable be revised in order to improve the ability of person capacity to cater to the passenger demand.

One of the significant findings that emerged from this questionnaire survey was that 73% of the respondents among car owners were willing to change their transportation mode from private car to the campus bus if the bus timetable was improved. The waiting time for bus arrival can be further improved but the overcrowded condition in the bus is the main issue complained by the respondents. The average passenger waiting time of bus arrival for both bus routes was between six and 15 minutes, which falls in the acceptable range. More than half of the respondents raise the issue of the overcrowded condition in the bus and most of them suggested increasing the bus service frequency of the current timetable.

More than half of the respondents are not satisfied with the current campus bus service. This is mostly due to the fact that there are not enough buses to cater to passenger demand and the condition onboard of buses is overcrowded. Most of the recommendations from the respondents were to increase the number of bus trips. Further analysis on passenger demand and person capacity showed that the recommendation by respondents to increase the bus service is reasonable.

5.1.2 Passenger Demand and Person Capacity

Passenger demand and person capacity were studied to identify the suitability of increasing the bus service frequency as suggested by the respondents of the questionnaire. The distribution of passenger demand is obtained by analysing the passenger count data. The current person capacity is scarce whereby the buses are overcrowded especially during peak hours. The bus trip departure times are misallocated, which causes resource wastage and low satisfaction level from the passengers.

Passenger load factor was used to identify the adequacy of person capacity, which affects the transit reliability and capacity. During peak hour periods, higher person capacity should be adjusted to fit the passenger demand distribution. Peak hour factor is used to study the variation of passenger demand during peak hours. By analysing the peak 20-minute in a peak hour, the variation of passenger demand during peak hour can be identified and the person capacity can be assigned accordingly. It is crucial to assign person capacity according to the passenger ridership distribution. Any oversupply or undersupply of person capacity will reduce the reliability and quality of the transit bus service.

Findings from the passenger demand and person capacity analysis enhance the justification of the outcomes from the questionnaire survey analysis. Results of the analysis also conclude that misallocation has occurred, where the current bus service is not able to handle the passenger demand. The undersupply of person capacity happens at peak hour and the oversupply of person capacity occurs at non-peak hour. This situation causes low passenger satisfaction level with long waiting time and an overcrowded bus. The passenger demand should be given attention so that a high performance and efficient on-campus bus service can be established. Thus, it is important to analyse the passenger count data with the bus dwell time, in order to identify the parameters that affect the performance of the transit bus service. Furthermore, a revised demand-based bus timetable is exceedingly needed to redress the inadequacy of the bus resources allocation.

5.1.3 Dwell Time Model

Multiple regression analysis is used to establish the dwell time models of the campus bus service. The variables that affect bus dwell time were statistically proven and expressed in the regression equation. Other than the number of boarding and alighting passengers, the station type, bus type used and PLF are other factors that affect dwell time significantly. Since the two-door bus and one-door bus have different maximum passenger capacity, PLF is used to measure the onboard crowdedness in the bus. The bus dwell time at the transportation hub is longer than at other stations. The two-door bus has a shorter dwell time than the one-door bus when both buses have the same number of passengers boarding and alighting.

Furthermore, the bus dwell time is also affected by the level of onboard crowdedness. Three models – low, medium, and high – were used to study the relationship between bus dwell time and the levels of PLF. The onboard friction created by passengers in a high passenger load bus slows down the passenger boarding and alighting time. A bus with higher passenger load will cumulatively affect the dwell time at remaining stations throughout the bus trip. This situation causes a higher trip time and degrades the transit speed and reliability.

Dwell time model analysis demonstrates the importance of implementing the correct and adequate bus type for an overall transit performance. PLF and bus type used are important factors that affect dwell time and can be controlled by the bus operator. The efficiency in terms of time is given the most consideration in a bus service evaluation. By assigning enough bus trips and the suitable bus type, the PLF value of a bus as well as dwell time can be reduced. The dwell time model is used in bus timetable optimisation to generate an optimal bus timetable that contains bus trip departure times and bus type used.

5.1.4 Bus Timetable Optimisation

The demand-based bus timetable is proposed by using bus timetable optimisation where the total dwell time and total passenger waiting time are reduced, which benefits passengers and the bus operator. The timetable is generated by using bi-objective optimisation, which minimises the total dwell time and the total passenger waiting time simultaneously. The bus timetable optimisation model by Li (2018) is used and slightly modified to suit the parameters in this study. Genetic algorithm is used in the bus timetable optimisation to generate an optimal bus timetable. The dwell time model from Section 4.3 is used to generate dwell times at all bus stations used in the bus timetable optimisation model.

The peak hours with higher person capacity are readjusted according to passenger ridership distribution. By establishing a bus timetable according to the passenger demand, the optimisation of the bus timetable will ensure that the person capacity assigned adheres to the passenger demand. This will also reduce the operating expenses, resource and manpower use for the operator. The proposed optimal bus timetable has been compared with the current bus timetable. The total bus dwell time and total passenger waiting time were reduced at least 12% and 20% respectively.

The proposed optimal bus timetable improves the transit reliability as well as the capability of transit capacity to cater to the passenger demand. Results from the questionnaire show that respondents had suggested increasing the number of bus trips in order to improve the performance of the current bus service. By using the timetable constructed with the bus timetable optimisation, the total number of bus trips can be reduced, but the total dwell time and total passenger waiting time will be reduced. Results clearly show the importance of assigning bus trip departure times according to the passenger demand distribution.

5.2 Contributions of Study

This study investigates the bus service performance in UM campus and identifies the methods to improve transit capacity, speed, and reliability. To encourage the university community to shift their transportation mode from private vehicles to the transit bus service, it is important to improve the current bus service reliability and capacity. Time efficiency is crucial in the evaluation of the campus bus performance, which includes passenger waiting time at bus stations and bus dwell time.

In this study, the relationship between bus dwell time and onboard crowdedness level is identified by using PLF. Most of the previous studies use dummy variable to represent the onboard crowdedness level when the bus is overloaded. Furthermore, three separate dwell time models are constructed to study the dwell time factors at different PLF levels. When a bus filled with more than half of the passenger capacity, result shows that dwell time is very sensitive to bus type used. This situation happened is due to the onboard friction among passengers. Bus operators are advised to use buses with suitable capacity to avoid longer dwell time, especially at peak hours. Moreover, most of the studies only focus on bus service with fare collections. This dwell time model is suitable for other free bus services, especially for campus bus service.

The bus timetable optimisation model of the present study can be used by the bus operator to devise solutions to minimise the time loss and improve the bus service satisfactory level. The bus operator can use the results of this study for better bus timetable planning that can satisfy the passenger demand.

5.3 Limitation of Study

The scope of the study is limited on campus bus service. The bus passenger data is collected manually. Due to the limitation on funding, this study is focus on bus service with small coverage service area. The impact on dwell time might be different for other bus service with bigger coverage area.

It is suggested that future study include bus service with wider coverage area with more collected sample. This will have a better view on bus passenger data and improve accuracy of the findings from bus dwell time model.

5.4 Recommendations for Future Research Direction

Future work will concentrate on the detailed investigation of the factors that can provide useful insight for efficient configurations of the transit bus system. While the study has shed some light on the determinants of the dwell time of the transit bus system, research can continue in the direction of a bigger-scale study in the future for areas such as the public bus system in Kuala Lumpur city centre. Moreover, more information on the passenger count data such as time interval between each boarding and alighting passenger would help to establish a detailed and higher-level study on bus dwell time.

Further investigations are needed to estimate the interaction effect among dwell time factors on the bus dwell time. For example, the interaction between the transportation hub and bus type is likely to affect dwell time. The effects of bus type on dwell time will be larger at the transportation hub compared to other station. In addition to the main effects of the transportation hub on dwell time, a further analysis of the effects of a two-way interaction is required, such as PLF with number of passengers boarding and alighting.

More broadly, research is also needed to take the other transportation modes into account rather than studying the bus system alone. The choice of transportation mode among a community is dependent on the transit reliability, infrastructure, economic concern as well as the coordination of modes of transportation at all levels throughout the system. For example, the modal share in public transportation is significantly influenced by private car ownership and deficiencies in the public transportation services. The increasing car ownership creates load pressure on the road network and subsequently causes road congestion. The road congestion, in return, restricts the movements of public transportation and degrades the reliability of the transit service. Thus, it is crucial to implement an integrated study to include all the transportation aspects, for example, the campus parking capacity, bicycle and pedestrian facilities, roadway facilities as well as bus transit services.

REFERENCES

Abkowitz, M., Eiger, A., & Engelstein, I. (1986). Optimal control of headway variation on transit routes. *Journal of advanced transportation, 20*(1), 73-88.

Abkowitz, M., & Engelstein, I. (1983). Factors affecting running time on transit routes. *Transportation Research Part A: General, 17*(2), 107-113.

Abkowitz, M., & Engelstein, I. (1984). Methods for maintaining transit service regularity. *Transportation Research Record, 961*, 1-8.

Abkowitz, M., Slavin, H., Waksman, R., Englisher, L. S., & Wilson, N. H. (1978). Transit service reliability: United States. Urban Mass Transportation Administration.

Abkowitz, M., & Tozzi, J. (1987). Research contributions to managing transit service reliability. *Journal of advanced transportation, 21*(1), 47-65.

Abreha, D. A. (2007). *Analysing public transport performance using efficiency measures and spatial analysis: The case of Addis Ababa, Ethiopia*.

Amin-Naseri, M. R., & Baradaran, V. (2014). Accurate estimation of average waiting time in public transportation systems. *Transportation Science, 49*(2), 213-222.

Arhin, S., Noel, E., Anderson, M. F., Williams, L., Ribisso, A., & Stinson, R. (2016). Optimization of transit total bus stop time models. *Journal of Traffic and Transportation Engineering (English Edition), 3*(2), 146-153.

Bell, M. G. (2001). Enhanced bus operations: The Curitiba model and its applicability to China. *Journal of advanced transportation, 35*(3), 199-214.

Bertini, R. L., & El-Geneidy, A. M. (2004). Modeling transit trip time using archived bus dispatch system data. *Journal of Transportation Engineering, 130*(1), 56-67.

Best practices in evaluating transit performance. (2014). Florida, U.S.: Florida Department of Transportation (FDOT), Freight Logistics and Passenger Operations, Transit Office.

Bian, B., Zhu, N., Ling, S., & Ma, S. (2015). Bus service time estimation model for a curbside bus stop. *Transportation Research Part C: Emerging Technologies, 57*, 103-121.

Campus Transportation Plan University of Massachusetts Lowell. (2011). Vanasse Hangen Brustlin Inc.

Campus Transportation System Evaluation. (2013). U.S.: University of Wisconsin - Madison.

Carreon, J. P., & Florendo, R. L. D. (2013). *Assessment of Public Transport Demand and Supply Characteristics for the UP Campus-Katipunan Route.* (Bachelor Bachelor), University of the Philippines Diliman.

Ceder, A., Hassold, S., Dunlop, C., & Chen, I. (2013). Improving urban public transport service using new timetabling strategies with different vehicle sizes. *International Journal of Urban Sciences, 17*(2), 239-258.

Chen, M., Liu, X., Xia, J., & Chien, S. I. (2004). A dynamic bus-arrival time prediction model based on APC data. *Computer-Aided Civil and Infrastructure Engineering, 19*(5), 364-376.

Crown, W. H. (1998). *Statistical models for the social and behavioral sciences: Multiple regression and limited-dependent variable models*: Greenwood Publishing Group.

Currie, G., Delbosc, A., Harrison, S., & Sarvi, M. (2013). Impact of crowding on streetcar dwell time. *Transportation Research Record: Journal of the Transportation Research Board*(2353), 100-106.

Daamen, W., Lee, Y.-c., & Wiggenraad, P. (2008). Boarding and alighting experiments: overview of setup and performance and some preliminary results. *Transportation Research Record: Journal of the Transportation Research Board*(2042), 71-81.

Davis, L. (1991). Handbook of genetic algorithms.

Demery Jr, L. W. (2005). An Analysis of Ridership Forecasts for the Los Angeles Metro Red Line: Alternative Strategies and Future Transit Improvements.

Doust, K. (2014). Toward a typology of sustainability for cities. *Journal of Traffic and Transportation Engineering (English Edition), 1*(3), 180-195.

East West Needs Study: Transport Supply and Demand (Existing and Future). (2006). Melbourne, Australia: Victorian Government.

Fernández, R., Zegers, P., Weber, G., & Tyler, N. (2010). Influence of platform height, door width, and fare collection on bus dwell time: laboratory evidence for Santiago de Chile. *Transportation Research Record: Journal of the Transportation Research Board*(2143), 59-66.

Fletcher, G., & El-Geneidy, A. (2013). Effects of fare payment types and crowding on dwell time: fine-grained analysis. *Transportation research record*, *2351*(1), 124-132.

Fritz, M. S. (1983). Effect of crowding on light rail passenger boarding times. *Transportation Research Record*(908).

Glick, T. B., & Figliozzi, M. A. (2019). Analysis and application of log-linear and quantile regression models to predict bus dwell times. *Transportation Research Record*, *2673*(10), 118-128.

Hale, C. A., & Charles, P. (2010). Practice Reviews in Peak Period Rail Demand Management: Munich & Washington DC.

Hartgen, D. T., & Horner, M. W. (1997). Transportation Publication Report 163: Comparative Performance of Major US Bus Transit Systems: 1988–1995: University of North Carolina at Charlotte.

Hashim, R., Mohamad, S., Haron, S., Hassan, F., Hassan, N., & Kasa, A. (2013). *Student satisfaction with the campus bus services at UiTM Shah Alam, Malaysia.* Paper presented at the 2013 IEEE Business Engineering and Industrial Applications Colloquium (BEIAC).

Henderson, G., Adkins, H., & Kwong, P. (1990). Toward a passenger-oriented model of subway performance. *Transportation Research Record, 1266*, 221-228.

Holland, J. (1975). An efficient genetic algorithm for the traveling salesman problem. *European Journal of Operational Research, 145*, 606-617.

Institute of Transportation Engineers. (2006). *Traffic Engineering Handbook* (6th ed.). Washington, DC United States Transportation Research Board.

Inta, M., & Muntean, A. (2015). Researches on reliability of urban passenger transport in Sibiu. *Annals of the Oradea university. Fascicle of Management and Technological Engineering*(1), 79-82.

Kaufman, D. E., & Smith, R. L. (1990). Minimum travel time paths in dynamic networks with application to intelligent vehicle/highway systems.

Krejcie, R. V., & Morgan, D. W. (1970). Determining sample size for research activities. *Educational and psychological measurement*, *30*(3), 607-610.

Li, X., Du, H., Ma, H., & Shang, C. (2018). Timetable optimization for single bus line involving fuzzy travel time. *Soft Computing, 22*(21), 6981-6994.

Lin, T.-m., & Wilson, N. H. (1992). Dwell time relationships for light rail systems. *Transportation Research Record*(1361).

Mallows, C. L. (1973). Some comments on C p. *Technometrics, 15*(4), 661-675.

Miles, J., & Shevlin, M. (2001). *Applying regression and correlation: A guide for students and researchers*: Sage.

Nakanishi, Y. J. (1997). Part 1: Bus: Bus performance indicators: on-time performance and service regularity. *Transportation Research Record, 1571*(1), 1-13.

Oi, S. Z. (2017). *Passenger supply and demand study of campus bus service in University of Malaya.* (Bachelor Thesis, University of Malaya, Kuala Lumpur, Malaysia).

Ólafsdóttír, Á. (2012). *Bus service performance analysis.: Case study: Bus line 1 in Stockholm, Sweden.* (Master Thesis, KTH Royal Institute of Technology, Stockholm, Sweden). Retrieved from http://www.diva-portal.org/smash/get/diva2:530934/FULLTEXT01.pdf

Parbo, J., Nielsen, O. A., & Prato, C. G. (2014). User perspectives in public transport timetable optimisation. *Transportation Research Part C: Emerging Technologies, 48*, 269-284.

Paulley, N., Balcombe, R., Mackett, R., Titheridge, H., Preston, J., Wardman, M., . . . White, P. (2006). The demand for public transport: The effects of fares, quality of service, income and car ownership. *Transport policy, 13*(4), 295-306.

Rajbhandari, R., Chien, S. I., & Daniel, J. R. (2003). Estimation of bus dwell times with automatic passenger counter information. *Transportation Research Record*, *1841*(1), 120-127.

Rodrigue, J.P., Comtois, C., & Slack, B. (2016). *The geography of transport systems*: Routledge.

Rodrigue, J.P., Notteboom, T., & Shaw, J. (2013). *The SAGE handbook of transport studies*: Sage.

Salicru, M., Fleurent, C., & Armengol, J. (2011). Timetable-based operation in urban transport: Run-time optimisation and improvements in the operating process. *Transportation Research Part A: Policy and Practice, 45*(8), 721-740.

Semeida, A. M. (2014). Derivation of travel demand forecasting models for low population areas: the case of Port Said Governorate, North East Egypt. *Journal of Traffic and Transportation Engineering (English Edition), 1*(3), 196-208.

Stopher, P. R. (1992). Use of an activity-based diary to collect household travel data. *Transportation, 19*(2), 159-176.

Strathman, J. G., & Hopper, J. R. (1993). Empirical analysis of bus transit on-time performance. *Transportation Research Part A: Policy and Practice, 27*(2), 93-100.

Sun, D., Peng, Z.-R., Shan, X., Chen, W., & Zeng, X. (2011). Development of web-based transit trip-planning system based on service-oriented architecture. *Transportation Research Record, 2217*(1), 87-94.

Sun, D. J., Xu, Y., & Peng, Z.-R. (2015). Timetable optimization for single bus line based on hybrid vehicle size model. *Journal of Traffic and Transportation Engineering (English Edition), 2*(3), 179-186.

Sun, L., Tirachini, A., Axhausen, K. W., Erath, A., & Lee, D.-H. (2014). Models of bus boarding and alighting dynamics. *Transportation Research Part A: Policy and Practice, 69*, 447-460.

Szplett, D., & Wirasinghe, S. (1984). An investigation of passenger interchange and train standing time at LRT stations:(i) alighting, boarding and platform distribution of passengers. *Journal of advanced transportation, 18*(1), 1-12.

Tong, C., & Wong, S. (1999). A stochastic transit assignment model using a dynamic schedule-based network. *Transportation Research Part B: Methodological, 33*(2), 107-121.

Traffic Data Collection and Analysis. (2004). Gaborone, Botswana Ministry of Works and Transport, Roads Department

Transit capacity and quality of service manual. (2013). (3rd ed.). Washington, D.C., U.S.: Transportation Research Board.

Turnquist, M. A. (1978). A model for investigating the effects of service frequency and reliability on bus passenger waiting times. *Transportation Research Record, 663*, 70-73.

Turnquist, M. A., & Bowman, L. A. (1980). The effects of network structure on reliability of transit service. *Transportation Research Part B: Methodological, 14*(1-2), 79-86.

Uyanık, G. K., & Güler, N. (2013). A study on multiple linear regression analysis. *Procedia-Social and Behavioral Sciences, 106*, 234-240.

Vissat, L. L., Clark, A., & Gilmore, S. (2015). Finding optimal timetables for Edinburgh bus routes. *Electronic Notes in Theoretical Computer Science, 310*, 179-199.

Wan, X., Wang, W., Liu, J., & Tong, T. (2014). Estimating the sample mean and standard deviation from the sample size, median, range and/or interquartile range. *BMC medical research methodology, 14*(1), 135.

Washington, S. P., Karlaftis, M. G., & Mannering, F. (2010). *Statistical and econometric methods for transportation data analysis*: Chapman and Hall/CRC.

Wilson, N. H., Nelson, D., Palmere, A., Grayson, T. H., & Cederquist, C. (1992). Service-quality monitoring for high-frequency transit lines. *Transportation Research Record*(1349).

Wirasinghe, S., & Szplett, D. (1984). An investigation of passenger interchange and train standing time at LRT stations:(ii) estimation of standing time. *Journal of advanced transportation, 18*(1), 13-24.

Woodhull, J. (1987). *Issues in on-time performance of bus systems*. Unpublished paper. Los Angeles, CA: Southern California Rapid Transit District.

Wooldridge, J. M. (2012). *Introductory econometrics: A modern approach* (5th ed.). USA: Nelson Education.

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*, 15-31.

Wu, Y., Yang, H., Tang, J., & Yu, Y. (2016). Multi-objective re-synchronizing of bus timetable: Model, complexity and solution. *Transportation Research Part C: Emerging Technologies, 67*, 149-168.

Xue, R., Sun, D. J., & Chen, S. (2015). Short-term bus passenger demand prediction based on time series model and interactive multiple model approach. *Discrete Dynamics in Nature and Society, 2015*.

Yan, S., Chi, C.-J., & Tang, C.-H. (2006). Inter-city bus routing and timetable setting under stochastic demands. *Transportation Research Part A: Policy and Practice, 40*(7), 572-586.

Yan, Y., Meng, Q., Wang, S., & Guo, X. (2012). Robust optimization model of schedule design for a fixed bus route. *Transportation Research Part C: Emerging Technologies, 25*, 113-121.

Yu, H., Ma, H., Du, H., Li, X., Xiao, R., & Du, Y. (2017). *Bus scheduling timetable optimization based on hybrid bus sizes.* Paper presented at the UK Workshop on Computational Intelligence.

Zhou, C., Dai, P., & Li, R. (2013). *The passenger demand prediction model on bus networks.* Paper presented at the 2013 IEEE 13th International Conference on Data Mining Workshops.

Zhou, P., Zheng, Y., & Li, M. (2012). *How long to wait?: predicting bus arrival time with mobile phone based participatory sensing.* Paper presented at the Proceedings of the 10th international conference on Mobile systems, applications, and services.

LIST OF PUBLICATIONS AND PAPERS PRESENTED

1. Gan, J. J., Yuen, C. W., Oi, S. Z., Mohd Rasdan Ibrahim, Goh, B. H., & Onn, C. C. (2018). Bus Timetabling Optimisation Method with Passenger Waiting Time and Dwell Time for Different Bus Passenger Capacity. *Civil Engineering and Architecture, 8*(4), 646-653. **(Published - 1st September 2020).**