PEDESTRIAN ROUTE CHOICE OF VERTICAL FACILITIES AT KUALA LUMPUR CITY CENTRE UNDERGROUND TRAIN STATION

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SCHOOL OF CIVIL ENGINEERING
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By

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I, ____ hereby

declare that I have checked and revised the whole draft of dissertation as required by my supervisor.

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ABSTRAK

Peningkatan bilangan pengguna Transit Aliran Ringan (LRT) Laluan Kelana Jaya mesti disokong dengan kemudahan pejalan kaki yang sempurna bagi memastikan pergerakan pejalan kaki berjalan lancar. Walau bagaimanapun, pilihan laluan keluar yang terhad di dalam stesen LRT bawah tanah dengan hanya melalui tangga dan eskalator menyebabkan kesesakan dan kelewatan untuk keluar dari platform terutama pada waktu puncak. Kajian ini membincangkan pilihan laluan pengguna stesen LRT bawah tanah Kuala Lumpur City Centre dengan mengunakan kaedah mengikuti pejalan kaki. Keputusan kajian menunjukkan pengguna LRT lebih cenderung menggunakan kemudahan yang dekat dengan pintu keluar keretapi yang digunakan, kecuali mereka yang keluar dari bahagian tengah keretapi cendurung memilih eskalator, hal ini menyebabkan peratusan pengunaan escalator (52.3%) lebih tinggi berbanding dengan penggunaan tangga (47.7%). Pengguna LRT berjalan lebih cepat sebanyak 31.5% semasa menghampiri laluan masuk tangga berbanding dengan eskalator. Ini kerana lebih ramai penumpang cendurung menggunakan eskalator dan kelajuan berjalan lebih rendah akibat kesesakan di depan eskalator. Oleh sebab itu, mereka mengalami masa kelewatan yang lebih tinggi sekurang-kurangnya 30.1% di laluan masuk eskalator berbanding dengan tangga. Namun, masa kelewatan yang dialami semasa berjalan atas tangga adalah lebih tinggi sekurang-kurangnya 48.8% berbanding dengan menggunakan eskalator kerana kelajuan pejalan kaki yang menggunakan eskalator dipengaruhi oleh kelajuan operasi eskalator. Kajian ini boleh membantu pengendali stesen memahami pilihan laluan pejalan kaki untuk keluar dari stesen bawah tanah dan boleh digunakan sebagai rujukan bagi mereka mereka bentuk stesen bawah tanah pada masa depan.

ABSTRACT

The increasing of ridership of Light Rail Transit (LRT) Kelana Jaya Line must be supported by efficient egress facilities in train station to optimise the pedestrian movement. However, limited route choices to egress platform level via stairways and escalators especially in underground train station are suspected to cause congestion and delay to egress the platform especially during the peak hours. In this dissertation, pedestrian route choice at Kuala Lumpur City Centre underground train station was studied by using Pedestrian Following Survey. The results showed that LRT users at the underground train station preferred to use the vertical facility that is nearer to their respective train doors due to the shortest path, except the passengers that alighted from the middle section of train and tended to egress with escalators over stairways, resulting in the percentage usage of escalators (52.3%) was higher than stairways (47.7%). LRT users at the underground platform walked faster towards stairways by at most 31.5% compared to the escalators. This is because pedestrians tended to use escalators thus reduced speed that caused by the overcrowded at the entrance of escalators. Hence, escalator users experienced higher delay in time by at least 30.1% compared to the stairway users. However, after the users boarded the vertical facilities, those who used stairways experienced higher delay time by at least 48.8% compared to those who used escalators that has uniform escalator operating speed. This dissertation can help the train station operators to have better understanding on pedestrian route choice to egress the underground train station and can be used as a reference for future facility design of underground train station.

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LIST OF ABBREVIATIONS

Name

LRT	**L**ight **R**ail **T**ransit
MRT	**M**ass **R**apid **T**ransit
KLCC	**K**uala **L**umpur **C**ity **C**entre

Unit

m/s	**M**etre per **s**econd

CHAPTER 1

INTRODUCTION

1.1 Background

Route choice is the pedestrian's decision of optimal path between an origin and a destination among a set of alternatives. Pedestrian route choice is dissimilar with drivers' route choice as the pedestrians have higher degree of freedom and randomness in choosing routes. Meanwhile drivers route choice always constraint of direction for manoeuvre, space of movement, fixed road and has restricted traffic rules. The understanding on pedestrian route choice behaviour is necessary for planning and design of pedestrian walking facilities especially in rail transit stations that serve thousands of daily ridership.

LRT Kelana Jaya Line has recorded the highest ridership among the existing rail transit in Klang Valley (Government's Initiative on Public Transport, 2017) and has the most direct impact from the Malaysia government with the effort of improving rail network system. Recent projects that have been launched include Light Rail Transit (LRT) Line Extension Project (LEP) connecting Ampang Line and Kelana Jaya Line by Putra Heights Station as interchange (LRT Line & LRT Extension, 2012) as well as Klang Valley Mass Rapid Transit Project (KVMRT) which is MRT Line 1, Sungai Buloh to Kajang Line (SBK Line) (The MRT Sungai Buloh-Kajang (SBK) Line, 2017). Government's initiative on public transport results in 12% of the overall daily ridership for existing urban rail in 2017 comparing to 2016 and even reached 30% after opening of MRT full line and the remarkable increment has happened at LRT Kelana Jaya Line with 26% increase of daily ridership (Government's Initiative on Public Transport, 2017). In addition to that, Kelana Jaya Additional Vehicle (KLAV) project has added new generation trains to LRT Kelana Jaya Line to reduce the waiting time and increase passenger capacity by 20% (New fleet to increase capacity, 2016).

Growing of ridership of LRT Kelana Jaya Line must be supported by efficient facilities in train station that meet the demand of riders to ensure fluent flow of pedestrians without any congestion at the bottlenecks. However, there is no sources claiming of upgrading the existing LRT train station. This urges the need of efficiency evaluation of the LRT stations especially underground LRT stations as limited route choice available to egress the underground platform level.

The stairway and escalator are the bottlenecks at underground platform level that determine a train station capacity due to their lowest capacity in the station (Campanella et al., 2013). If similar route is taken by pedestrians to egress from underground platform via vertical facility, this causes pedestrians crowded the entrance of vertical facility and results in congestion (Daamen et al., 2005). Pedestrians should be distributed over different routes in the station to optimize the efficiency of facilities and ensure the pedestrian comfort, therefore encouraging use of public transport.

However, limited studies in Malaysia are conducted to study the pedestrians' behaviour at underground train stations. Hence, this dissertation investigates the pedestrians' route choice of vertical facilities to egress the underground platform level to concourse level after alighting from train. The study of pedestrians' preference of vertical facilities helps the train station operator to understand the pedestrians' behaviors towards the existing design of facilities involving locations of escalator and stairway in an underground train station. The dissertation uses Viswalk to simulate the route choice behaviours of pedestrians at underground station to have better understanding of pedestrians' behaviour.

1.2 Problem Statement

KLCC underground train station is located beneath a shopping mall, Avenue K. This underground train station has a pedestrian subway connecting to Suria KLCC and to the rest of commercials, retails, business and financial centres, hence it has become one of the busiest train stations, serving more than 37,000 daily ridership according to the report provided by Prasarana Sdn. Bhd.

The number of ridership at train station will increase if KLCC Convention Centre hold functions. In addition, MRT Line 2, Sungai Buloh-Serdang-Putrajaya Line (SSP Line) will commence service on July 2022 and one of its underground station, KLCC East MRT Station will be located a short distance from KLCC LRT underground train station (The MRT Sungai Buloh-Serdang-Putrajaya (SSP) Line, 2017). The SSP Line and LRT Kelana Jaya Line are shown in Figure 1.1. It is believed to boost the ridership of KLCC LRT underground train station after its commencement of service. Hence, the existing facilities in KLCC LRT underground train station should be reviewed and evaluated.

The passengers composed of office workers and travellers has caused congestion at the underground platform level and the congestion situation is even worse during peak hours. The excessive demand of pedestrians to egress the underground station via vertical facilities caused these bottlenecks overflowing with pedestrians especially at the entrance of escalator. The route choice of pedestrians to egress could have contributed to the excessive demand on one of the vertical facilities at underground platform level.

Therefore, the study on the route choice of pedestrians from each train door to the egressing vertical facilities should be conducted to review whether the existing layout of KLCC underground station influences the route choice of pedestrians.

The common route taken by the pedestrians causes overcrowding and leads to congestion which in turn incurring additional pedestrians’ walking costs at underground train station. Hoogendoorn et al. (2015) explained additional walking costs was stemmed from delay of pedestrians caused by reduced walking speeds due to high pedestrian densities. Therefore, it is interested to investigate the delay time caused by the route choice of pedestrians to egress via vertical facilities during peak hours and non-peak hours.

In a nutshell, the investigation of the route choice of pedestrians to egress the underground platform level via vertical facilities can review the existing layout of KLCC LRT underground train station and help the station operators to have better understanding of pedestrian behaviours inside underground station.

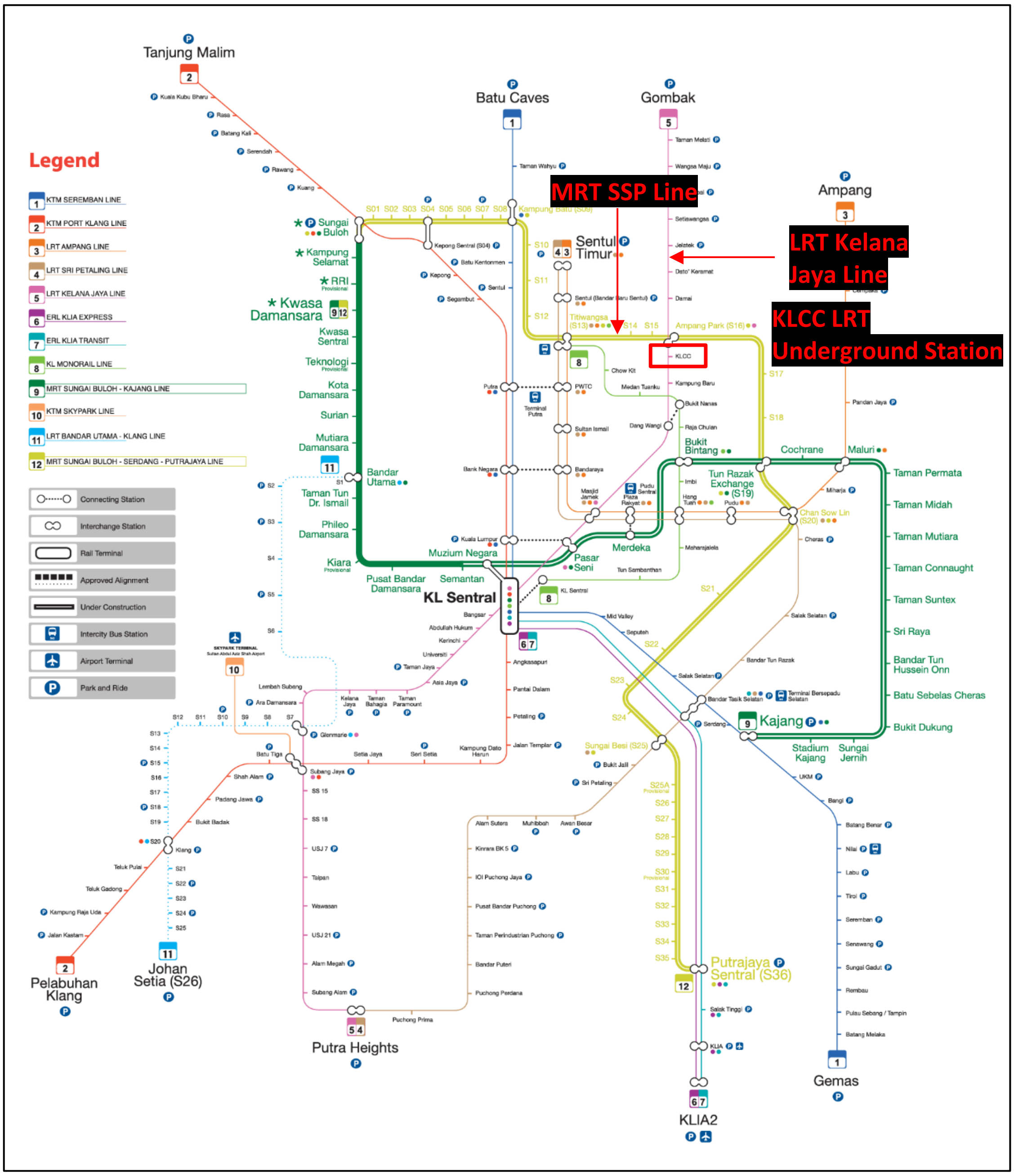

Figure 1.1: Klang Valley Rail Transit Map (Explore Klang Valley Rail Transit Map, n.d.)

1.3 Objectives

The objectives in this study are:

1. To determine the proportion of LRT passengers using stairway and escalator to egress the platform level at the underground train station.
2. To perform verification and validation of Viswalk based on pedestrian behaviour at the underground train station.
3. To simulate the delay time that occurred with the pedestrian route choice at the underground train station.

1.4 Scope of Work

This dissertation focuses on the pedestrians' route choice of vertical facilities to egress from platform level to concourse level during peak hours and non-peak hours in KLCC underground train station. The study areas that consider for the simulation involved the platform level and vertical facilities only. The period of simulation included peak hours include morning, afternoon, evening peak hour and non-peak hours.

In terms of vertical facilities, this study concerns on escalator and stairway only, therefore the route choice to use escalator and stairway are examined. Pedestrian route choices at the platform level are observed and recorded to determine their travel time to complete the chosen path from the train doors to the vertical facilities. The data collection only considers the passengers who egress the platform, thus the route choice from the vertical facilities to the train doors are not being analysed in this study.

The walking speed is determined regardless of personal attribute such as age, gender and individual or group. The pedestrians with difficulty in walking, visually impaired or requiring special guidance such as children are also not included in the walking speed survey.

1.5 Dissertation Outline

This thesis comprises five chapters. Chapter 1 is the introduction of the topic explaining the relevant background and previous studies, problem statement, objectives and scopes of the study; Chapter 2 is the literature review focusing on the relevant previous studies on pedestrian's route choice, walking characteristics and simulation of pedestrian behaviours which provide necessary information for topic background, methodology and outcome of the thesis: Chapter 3 is the methodology of the study describing the flows and steps to obtain the result for the dissertation; Chapter 4 is the data analysis and data presentation which sort out the data obtained from data collection at KLCC LRT underground station and simulation by Viswalk Software. The data is then analysed and discussed; Chapter 5 is the chapter concluding the findings from the study. The limitation in the study is reviewed, hence, suggestion and recommendation could be a reference to relevant further studies on pedestrians' route choice and simulation of pedestrians' behaviour.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter reviewed the previous studies that have been done on pedestrian behaviour and pedestrian simulation which were vital in developing better understanding to perform the research work in this dissertation. The topics were discussed in this chapters included pedestrian route choice at horizontal and vertical facilities, pedestrian walking speed, pedestrian following survey as well as pedestrian simulation.

2.2 Pedestrian Route Choice

Hoogendoorn and Bovy (2004) described pedestrian walking behaviour in three levels which were strategic level, tactical level and operational level. Strategic level involves pedestrian determining a set of activity pattern and setting their departure time whereas operational level is the pedestrian walking to reach the destination with adhering the planned route. Meanwhile, pedestrian route choice is the tactical level of pedestrian behaviour which decision input by external factors (environment) and internal factors (pedestrian personal attribute) as well as anticipated traffic conditions ahead.

Pedestrian route choice is differentiated from other modes of transport due to pedestrian route is continuous trajectories in time and space (Hoogendoorn and Bovy, 2004). This is due to pedestrian movement is in two dimensions (x and y directions) whereas other transports such as car movement is in one dimension (x direction only) (Hoogendoorn, 2011).

Besides, the differences between vehicular traffic and pedestrian traffic are pedestrians moving in multiple directional flow whereas vehicles travelling in single directional flow, pedestrians' behaviour during interaction with others is driven by subconscious while interaction of vehicles are strongly affected by rules (Hoogendoorn, 2011). Gräßle and Kretz (2011) stated pedestrian route choice is more complicated than vehicle route choice as vehicle drivers strongly prefer the quickest path whereas the pedestrians incline towards the quickest route with safer and more attractive.

The understanding of pedestrian's decision on route choice decision is important as the collective route choice decision of all individual pedestrians can affect the quality of the environment where they are situated, the typical example of demeriting environmental quality is congestion (Bovy and Stern, 2012). There are many researches using the knowledge of pedestrian route choices to review the existing building layout and propose the optimal solution to solve the crowdedness.

Broach and Dill (2015) studied the characteristics of route choice by using revealed preference of GPS data. The findings revealed that pedestrians were likely to choose more attractive facilities but their tolerance for detours was limited. Pedestrians preferred to walk at commercial streets compared to alleyways and unpaved streets, unless they can save up large distance. The authors claimed that the study helped to understand people willingness to select a path which avoided negative features and experience positive features along a route.

Xu et al. (2015) stated that the pedestrians inclined to select route with minimum disutility. They utilised the utility function to solve the pedestrian crowdedness access to platform level by closing the escalators, which are the route with minimum disutility, hence forcing the pedestrians to use stair and increasing waiting time of these pedestrians.

The results showed passenger flow was diminished further and remained below 800 pedestrians at platform during peak hours.

Li et al. (2016) established pedestrian choice model of vertical facilities with the consideration of interlayer height, luggage, the difference between queuing pedestrians as well as walking speed support vector machine and added into the pedestrian simulation model using cellular automata to simulate the pedestrian choice behaviour. They simulated the pedestrian choice behaviour to improve the existing layout of Changchun Light Rail Transfer Station by dividing the ascending and descending escalators with stairway in the middle, hence reducing the conflicts between escalator pedestrians from opposite direction and proved by the decrease of travel time with improved layout as shown in Figure 2.1.

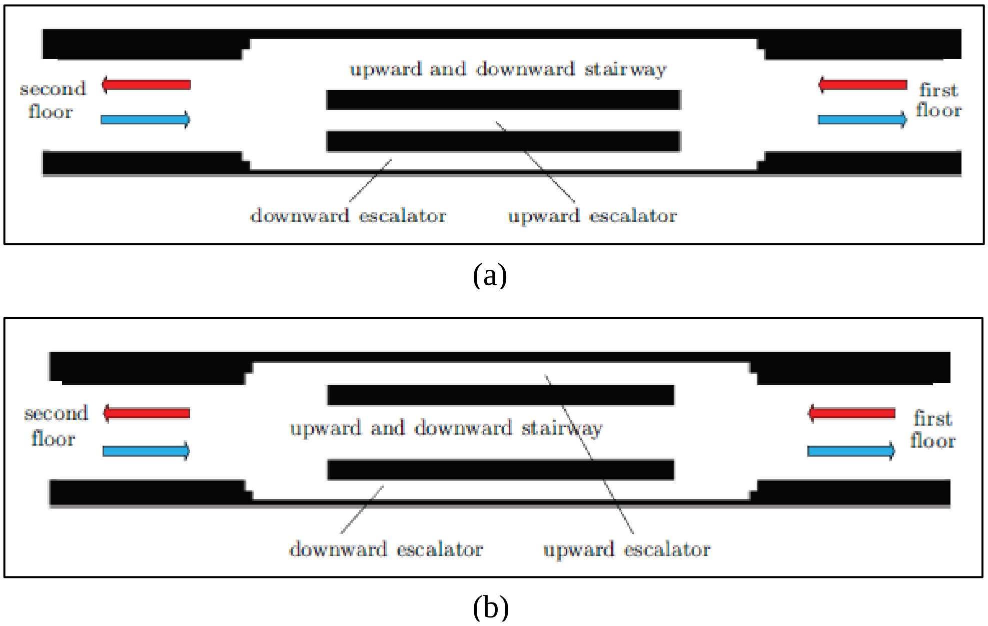

Figure 2.1: Simplified layout of Changchun Light-Rail Transfer Station: (a) Existing layout; (b) Improved layout (Li et al., 2016)

2.3 Factors Influencing Pedestrian Route Choice

Pedestrians prefer route with shorter distance, shorter travel time, more than one trip attractors and connected links, less crossings and barriers, medium level of congestion less than 20 pedestrians per minute as well as safe and pleasing walking environment (Hewawasam et al., 2013). However, pedestrians would trade off the walking distance and time with additional walking effort such as climbing steps and crossing a road (Olszewski and Wibowo, 2005). Pedestrian environment will affect walking utility with the attractions (amenities, shops and parks) and obstacles (hilly topology and size of sidewalks) and subsequently influence pedestrian route choice (Guo, 2010).

The pedestrian route choice at platform level of a transit station is further including train stop location alongside the platform and orientation of vertical facilities (Ton et al., 2015). Meanwhile, the pedestrian route choice at shopping centres consider combination of distance and shop window attraction (Werberich et al., 2016).

Daamen et al. (2006) studies the pedestrian route choice between stairs, escalators and ramps in two Dutch train stations by following passengers through the facility from origin to destination. However, they found the choice behaviour respect to gender, ages, with or without luggage did not show any distinct different route choice except senior passengers who prefer to use shorter routes nearly eight times than adults. Same findings agreed by Galama (2016) who focused on factors influencing pedestrian route choices by conducting online survey and GPS-trackers and the results indicated age, gender and pedestrian group size had little influence on the route choices and insignificant at 0.05 level.

2.4 Pedestrian Route Choice of Vertical Facilities

A building consists of vertical and horizontal facilities connecting together offering numerous of route choices to the pedestrians. Nonetheless, there are slightly difference in pedestrian decision between route choice of vertical facilities and route choice of horizontal facilities. The vertical facilities in a building are usually escalator and stairway. The effort of climbing a grade is considered in pedestrian decision-making of path besides the shortest travel time as well as shortest travel distance (Cheung and Lam, 1998).

Zhang et al. (2015) focused on pedestrian route choices between escalator and stairway at Xinjiekou station, Gulou station and Nanjingzhan station and discovered the number of pedestrians alighted the train near the escalator chose escalator was higher than pedestrians near the stairway choose stairway.

Meanwhile, Andersen and Bauman (2011) investigated the influence of commuter pedestrian traffic on the use of stairs in a subway station and recorded only 11.2% commuters ascended with stairs during least heavy commuter traffic period and increased to 18.7% and 20.8% for moderate and high commuter traffic flow.

Lazi and Mustafa (2015) studied the pedestrian route choice to descending at Masjid Jamek Terminal and revealed more than 90% of pedestrian utilised escalator to descend rather than stairway every day. The use of stairway was higher during morning than evening. The findings of Lazi and Mustafa (2015) is summarized in Figure 2.2.

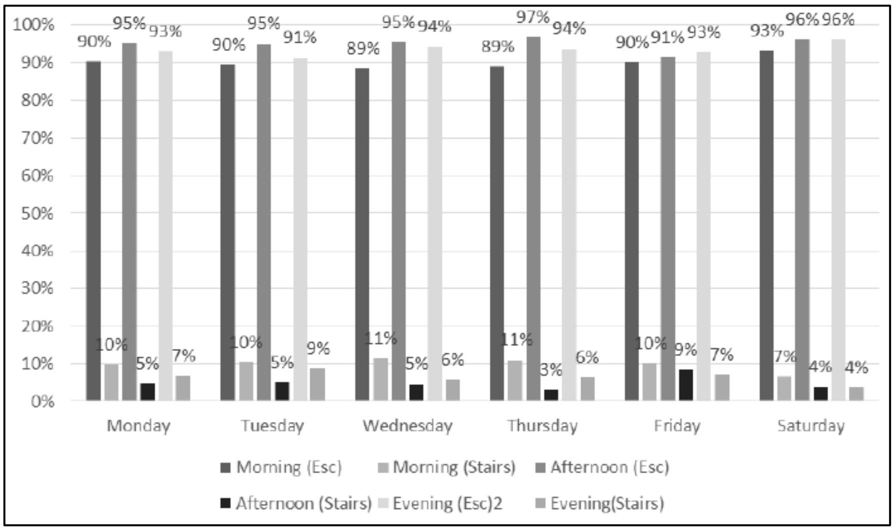

Figure 2.2: Percentage usage of facilities (Lazi and Mustafa, 2015)

Zacharias and Tang (2015) studied the impact of vertical facilities' location, height and pedestrian volume towards the pedestrian's choices between stairs and escalator with selecting 15 stairways, 14 and 13 respective to ascending and descending escalators in 13 public areas in Beijing during middle of the day, from 10am to 5pm. The results showed that stair climbing accounted for 25.4% of total ascending volume and 32.8% for descending. They discovered the increase in the distance between stairway and escalator had promoted the stair climbing and the increase of height between floors had demerited the use of stair climbing. Besides, people preferred to take stairway to descend compared to ascending when the pedestrian volume increased at escalator due to lower expenditure of energy required to descend.

Srikukenthiran et al. (2013) developed a set of logistic regression models which explained transit users uses of escalator and stair by collecting extensive data at co-location of these facilities in six subway station in Toronto. The model revealed that the pedestrians tend to use escalator when there was opposing flow in staircase. Besides, pedestrian strongly preferred to use escalator for ascending regardless of facility height.

However, the preference of escalator usage is highly influenced by facility height in descending direction.

Daamen et al. (2006) studies the pedestrian route choice between stairs, escalators and ramps in two Dutch train stations by following passengers through the facility from origin to destination. They discovered that escalator was the most preferred facility, followed by ramp and the least preference went to stairway owing to the walking time on stairway was 1.86 times slower than walking on a level facility whereas walking on ramp and escalator were only 1.37 and 1.28 times slower than using level facility.

Ji et al. (2013) investigate the pedestrian choice behaviour using random utility theory and floor field cellular automata. They revealed that during congested situation, pedestrians tend to choose stairways as they are very familiar and under very high time pressure. When the pedestrians were unfamiliar with the facilities, the probability of choosing escalator was low and almost equal to the probability of using stairway. Besides, the finding also showed the probability of pedestrians using escalator is smaller in congested situation than in uncongested situation.

Cheung and Lam (1998) investigated the pedestrian behaviour in choosing between escalators and stairways in Hong Kong Mass Transit Railway (MTR) stations during peak hours. Their data indicated than the escalator usage would never below 60%. Besides, they discovered that pedestrians were more sensitive to the relative delay on a descending facility than on an ascending facility such that 85% of pedestrians will take escalator when the relative delay was up to 7.8s in descending direction, in contrast, 17.4s was acceptable for the ascending directions.

The findings of Li et al. (2014) also agreed with findings of when the delay time shift from 10 to 20s or more, the pedestrian will shift to take stairway and even 98%

pedestrians prefer stairway when delay time reached 30s. The study of Zhang et al. (2015) concluded more pedestrians tended to use stairway rather than escalator with the increase of pedestrian flow and delay time. In addition, they found the upward pedestrians in Gulou station were less sensitive to delay time on escalator than Xinjiekou Station and Nanjingzhan station due to great floor height at Gulou station that required more effort to climb stairway.

2.5 Pedestrian Walking Speed

2.5.1 Pedestrian Walking Speed at Horizontal Facilities

Pedestrian walking speed is the fundamental to any roadway and traffic control design. Goh et al. (2012) showed the pedestrian walking speed at non-signalised crosswalk was significantly faster than that at signalised crosswalk in Malaysia. The mean, 85^{th} percentile and 15^{th} percentile of pedestrian speeds for non-signalised crosswalk were 1.39m/s, 1.63m/s and 1.15m/s respectively whereas for signalised crosswalk were 1.31m/s, 1.53m/s and 1.09m/s respectively.

Azmi et al. (2012) compared the walking behaviour between urban and rural residents in Malysia and the result showed the male teenagers and adults walked with 1.45m/s in rural neighbourhood while female primary school children even walked faster with 1.46m/s. Bohari et al. (2014) studied the pedestrian movement at Masjid Jamek Interchange, Malaysia and the recorded walking speed was ranging from 0.22m/s to 1.34m/s for female pedestrians and 0.75m/s to 1.5m/s for male pedestrians who walked slightly faster. Mustafa et al. (2015) studied the pedestrian movement at ticketing gate at one of Malaysia railway station and reported pedestrian mean speed of 0.60 m/s during peak hours and 0.61m/s during non-peak hours due to the bottleneck at the ticketing gate.

Zhang et al. (2009) found that the pedestrian walking speed was the fastest in platform with train arriving with mean 1.62m/s and 1.49m/s for walking speed at platform without train which is still higher than the mean speed at passageway, 1.33m/s.

Lam and Cheung (2000) reported free flow speeds and speed at capacity as summarized Table 2.1. At the same time, they discovered the maximum density at platforms for Mass Transit Railway (MRT) and Kowloon-Canton Railway (KCT) was higher than the concourse due to pedestrian movement at concourse level was multidirectional whereas pedestrian movement at platforms was majorly bidirectional flow resulting in maximum flow rates.

Table 2.1: Walking speed of pedestrian facilities in railway station (Lam and Cheung, 2000)

Pedestrian Facility	Mass Transit Railway (MRT)		Kowloon-Canton Railway (KCT)	
	Free Flow Speed (m/s)	Walking speed at capacity (m/s)	Free Flow Speed (m/s)	Walking speed at capacity (m/s)
Passageway	1.37	0.61	1.32	0.60
Concourse (straight ahead movement)	1.25	0.40	1.27	0.40
Concourse (turning movement)	1.28	0.45	1.29	0.43
Platform	1.30	0.58	1.28	0.56

Lagervall and Samuelsson (2014) described flow level for average 960 pedestrians per hour as low flow and average 2760 pedestrian per hour as high flow. Pedestrians at low flow level time between 7.25am to 8.10am tended to walk faster than high flow level which happened between 4.30pm to 5.15pm in Stockholm Central

Station. The average walking speed at low and high flow levels were 1.33m/s and 1.25m/s respectively.

2.5.2 Pedestrian Walking Speed at Vertical Facilities

Sharifi et al. (2015) explained that pedestrian free flow speed (0.62m/s) and speed at capacity (0.14m/s) at the stairway was the lowest compared to other horizontal environments due to pedestrian movement was constrained by the complex characteristics of stairway environment such as tread size, hence they were unable to maintain their desired speed.

Patra et al. (2017) obtained average walking speed of 0.70m/s at stairway of Secunderabad Railway Station, India that is even higher than average walking speed at passage with or without centre rail which were 0.59m/s and 0.47m/s. They observed that pedestrians tend to follow the predecessor without any overtaking, in contrast, pedestrians completed walking at stairway without stopping and changes of direction where there was space.

Chen et al. (2010) discovered that the level passageway almost twice the free flow speed of the stairways in Shanghai, China, Metro Stations, with pedestrian's walking step at level passageway equalled to two steps at stairway. It was interested that the free flow speed of two-way stairway was ranged between that of ascending and descending stairways as summarized in Table 2.2.

Table 2.2: Walking speed at pedestrian facility in metro station (Chen et al., 2010)

Pedestrian Facility	Free-Flow Speed (m/s)
Level passageway	1.35
Ascending stairway	0.63
Descending stairway	0.77
Two-way stairway	0.70

Sharifi et al. (2014) reported that the mean walking speed of homogenous population in stairway is 0.56m/s that higher than heterogenous population which is 0.43m/s by 23%. The counterflow had the most impact on reducing the population walking speed at stairway compared to the other pedestrian facility as shown in Figure 2.3.

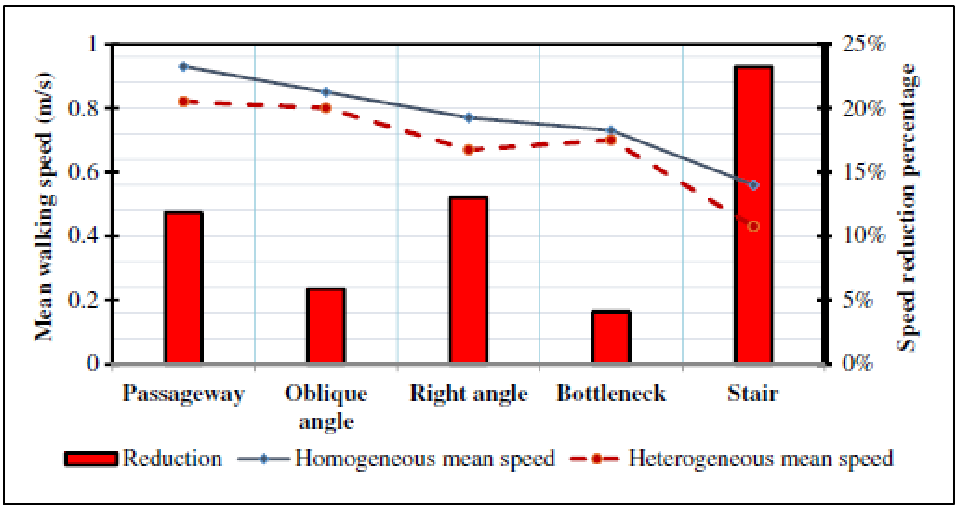

Figure 2.3: Mean walking speed of homogeneous and heterogenous populations in different walking environments (Sharifi et al., 2014)

2.6 Pedestrian Following Survey

Pedestrian Following Survey (PFS) is a survey technique based on the idea of observing traffic by a moving observer which is extended from floating car data (FCD) applying on studies of pedestrian traffic. Soltész et al. (2017) states that PFS is based on two simultaneous measurements which the first group of observers follow randomly selected pedestrians appear from the access point until reaching egress point in an enclosed area while the second group counts the traffic volume of access points to determine population. PFS can survey the origin and destination of pedestrians without causing any disturbance.

Meanwhile, Daamen and Hoogendoorn (2004) used the pedestrian following survey for the data collection at a platform of Delft Station to validate pedestrian flow modelling in SimPed with three types of observations. First observation was the alighting and boarding process with focusing on the number of boarding and alighting passengers per door and per train; second observation was individual activity with focusing on individual walking time on stair and on platform as well as the start and duration of activities such as purchasing ticket or reading information board; third observation was density on part of the platform with concerning on average of passengers present within a specific period. They divided the platform into areas with length of 10 metres as shown in Figure 2.4 to ease the data collection.

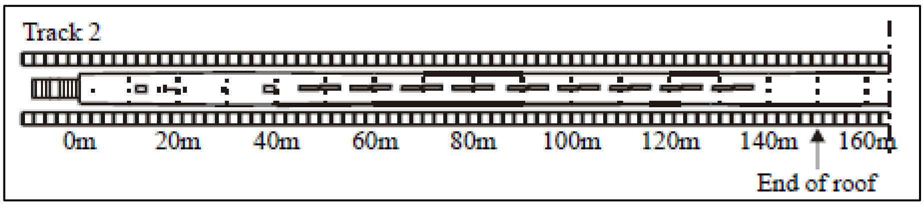

Figure 2.4: Section division for pedestrian following survey at Delft Station

Daamen et al. (2006) investigated the route choice of pedestrian between stairs, escalators and ramps in in two Dutch train stations by following passengers through the facility from origin to destination while collecting the personal characteristics such as gender and age as well as recording the route taken by the pedestrian from an entry point to the exit point.

Young (1999) studied the pedestrian movements in various airport terminal corridors with and without moving walkways. The study collected data by following randomly selected parties of passengers through corridor and observe the pedestrian in the aspect of age, gender type, party type, number of bags carried well as travel type as well as travel time. The data collection was further assisted by video recording.

2.7 Pedestrian Simulation

A lot of pedestrian simulation has been done to study pedestrian behaviour with the walking environment. Jaros et al. (2016) analysed and structured the pedestrian behaviour in buildings to develop a behavioural model for buildings with high pedestrian flow. This model able to simulate the pedestrian flow with providing the visual feedback for layout and dimensions regarding floor space, maximum capacities, unused and congested areas, high collision areas and general space organisation. Pedestrian simulation can be used as a planning tool. Lee (2015) used pedestrian simulation software, Viswalk to determine the delay time of shopping mall pedestrian during construction and utilized ant algorithm to find out the minimum delay time schedule plan, hence picked up the best schedule plan for the benefits of owners and users in shopping mall.

Microscopic models simulates pedestrian flow at the level of individual pedestrians which generally aim to describe the individual behaviour and interactions (Hoogendoorn et al., 2015) with the microscopic characteristics such as pedestrian speed, acceleration, time headway and distance headway (Hoogendoorn, 2011), in contrast, macroscopic models describe the flow dynamics in pedestrian aggregate behaviour using quantities such as flows, densities and speeds. PTV Group Viswalk is based on the social force models to reproduce the pedestrian behaviour.

2.7.1 Social Force Model

Social force model is a continuous model with Newtonian mechanics (Johansson, 2009) and based on the concept the motion of pedestrians (Helbing and Molnar, 1995) as result of human beings who are subjected to forces and motivating them to move in a certain direction. The forces leading the pedestrians to accelerate and decelerate that compose of driving force in the desired direction, social forces between pedestrians which pedestrian wants to keep a distance from other pedestrians especially strangers as well as repulsive forces from objects that pedestrian keeps a distance to avoid collision. Laufer (2008) illustrates the forces apply with social force model in Figure 2.5.

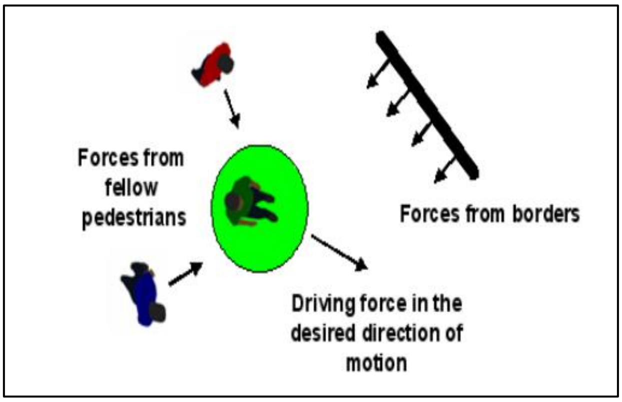

Figure 2.5: Illustration of social force model by Laufer (2008)

Viswalk accounted random force which terms as noise in the modified social force model to prevent deadlocks at bottlenecks (Friis and Svensson, 2013). Therefore, with these forces, pedestrians can automatically self-organising themselves and walking in the same direction in lanes when an opposing flow is exist (Laufer, 2008). PTV Viswalk is built on the combination of two variants which are circular specification and elliptical specification II of the modified social force model which affect the pedestrians in relation to each other as well as objects in the environment (Blomstrand Martén and Henningsson, 2014).

2.8 Viswalk

Viswalk is a leading software for pedestrian simulation (PTV, 2014). It is designed for the users interested pedestrian traffic modelling for purpose of building design, pedestrian traffic, event planning as well as fire and evacuation management.

2.8.1 Viswalk Pedestrian Behaviour Settings

Viswalk allows users to define the pedestrian input and pedestrian route choice (PTV, 2014). By default, the pedestrians choose the shortest path to reach the users' defined destination which known as *static potential*. The pedestrian routing decision can be adjusted either *static* or *partial* and even could have some intermediate destinations before reaching the final destination. *Dynamic potential* allows pedestrian to reach the destination with the quickest path that determined from minimum travel time and not necessarily the shortest path. The description of pedestrian walking behaviour parameters is summarized in Table 2.3 from Svensson (2013) and PTV (2014).

Table 2.3: Desciptions of walking behaviour parameters

Parameters	Descriptions
Tau (τ)	Relaxation time which is the response time related for the acceleration of pedestrian. By decreasing tau, the acceleration and driving force increase which allows better flow through bottleneck with increasing density.
ReactToN	The maximum number of pedestrians that are taken into consideration of calculating total force for a pedestrian. The decrease of *ReactToN* value can increase the density at the bottleneck leading to formation of the group.
Lambda Mean (λ)	*Lambda* governs the degree of anisotropy of the forces which affects the social force. Increase of *Lambda* makes the pedestrians pushing each other and results in efficient counter flow as well as flow through the bottleneck which is depending on the size of jam.
ASoclso and *BSoclso*	These parameters govern the direction dependency force between two pedestrians. Increase of the values of *ASoclso* and *BSoclso* will lower the density at the bottleneck and obtain higher headway between passengers.
ASocMean and *BSocMean*	These parameters govern the strength and range of speed-dependent social force between pedestrians. The increase of values will give the same effects as *ASoclso* and *BSoclso*.
VD	*VD* is expressed in second which decides when to evade the opposite pedestrian.
Noise	Random force term which is added to total force calculated only if a pedestrian is slower than his or her desired speed for a certain time. Increase of *Noise* can prevent deadlock of pedestrians at narrow bottleneck.

2.8.2 Verification and Validation of Pedestrian Simulation

International Standards Organization (2015) states verification is a process to determine the relevant equations and calculation methods of a model is implemented correctly whereas validation is a process to identify the calculation methods used able to accurately represent the real world.

Ronchi et al., (2013) proposed a set of tests and recommendations for the verification and validation of building evacuation models. Verification tests consist of quantitative evaluation and qualitative evaluation of the model results. Quantitative evaluation involves expressing the percentage differences between the expected results and simulation results whereas qualitative evaluation relies on observation of an expected behaviour. Validation tests involve comparison between model predictions and the experimental data based on suggested variables.

Blomstrand Martén and Henningsson (2014) adopted test procedures proposed by Ronchi et al. (2013) to verify and validate Viswalk for building evacuation modelling. The qualitative tests included pre-evacuation time distributions, speed on corridor, speed on stair and assigned occupant demographic to determine the ability of Viwalk to reproduce the defined specification. Blomstrand Martén and Henningsson (2014) stated that the walking speed of a pedestrian was measured along the incline of the stairs. The quantitative tests performed with pedestrian movement around a corner, horizontal counter flow and pedestrian congestion to observe the ability of Viswalk to simulate the expected pedestrian behaviours.

Blomstrand Martén and Henningsson (2014) validated the Viwalk by simulating pedestrian behaviours with standard Viswalk settings and user-defined settings to compare which settings can produce the result that similar with the experimental data, the variables used to compare between experimental data and simulation data was pedestrian flow and movement time. However, this study did not define an acceptance criterion for validation. However, they concluded Viswalk able to predict and reproduce pedestrian with given situation with result of simulation of using specified settings,