



**MODELING PEDESTRIAN FLOW IN TRANSIT STATIONS:
A CASE STUDY OF TRANSIT STATIONS IN BANGKOK**

BY

MR. PUVIT BOONSOMPARN

**A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE
(ENGINEERING AND TECHNOLOGY)**

SIRINDHORN INTERNATIONAL INSTITUTE OF TECHNOLOGY

THAMMASAT UNIVERSITY

ACADEMIC YEAR 2019

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THESIS

BY

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ENTITLED

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was approved as partial fulfillment of the requirements for
the degree of Master of Science (Engineering and Technology)

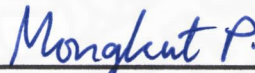
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Thesis Title	MODELING PEDESTRIAN FLOW IN TRANSIT STATIONS: A CASE STUDY OF TRANSIT STATIONS IN BANGKOK
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Degree	Master of Science (Engineering and Technology)
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ABSTRACT

The railway is one of the most important modes of transportation to avoid traffic congestion on the road in many developing countries. In Bangkok, the most attractive transportation mode is railway. Simulation technology is key to generate and virtualize situation that could be used to forecast and evaluate the safety. This study considers pedestrian movement and pedestrian simulation in transit stations. Due to a lack of the study of the pedestrian behaviors and pedestrian simulation in Thailand. The objectives of this study are to survey and identify standard parameters for pedestrian simulation. Besides calibration, the parameter sets in both case scenarios include normal situation and evacuation. Data for modeling pedestrian movement were collected from on-site survey at MRT Huai Khwang station by using manual counts and video cameras. The results were separated into three parts: 1) the survey data, 2) the parameter calibration, and 3) the parameter sets validation. The result of the on-site survey showed that the facility dimension satisfies the National Fire Protection Association (NFPA) standards of the facility in the transit station. On the other hand, the information about pedestrians was collected from video cameras including the frequency of both directions in a train's trip. The parameters of pedestrian behavior in VISSIM/VISWALK software were calibrated to fit the survey data by grid analysis method. The calibration applied into

four criteria including pedestrian walking speed, time used by pedestrians to pass through the bottlenecks, flow of pedestrians passes through the opposite direction and time spent by pedestrians in queues. Using sum square error (SSE) the calibrated parameter provided an average error of 1.53 percent. While the validation of parameter sets was performed by using the MRT Sukhumvit station. The results were compared with the parameters from previous studies. The validation result showed that the average error (3.88 percent) by using the calibrated parameter set in this study was minimum among previous studies. Moreover, the parameter set for pedestrian evacuation was calibrated by using the evacuation experiment data. The simulation of evacuation was conducted to compare the evacuation time from Huai Khwang station to the NFPA standards and the Ministry of Interior Regulations in Thailand. The results reveal that the evacuation time in both scenarios (base case scenario and worst case scenario) satisfies both the requirements at the peak 15-min volume in 2019 and 2027. The findings from this study could be a guideline for the simulation of pedestrian behaviors in Thailand. The recommendation should be additional emergency exits at the fare collection gate to overcome the ridership growth.

Keywords: Pedestrian Flow, Pedestrian Simulation, Transit Station, Evacuation Model, VISSIM/VISWALK software

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LIST OF SYMBOLS/ABBREVIATIONS

Symbols/Abbreviations	Terms
AI	Artificial Intelligence
AIMSUN	Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks
ARL	Airport Rail Link
ANOVA	Analysis of Variance
BMA	Bangkok Metropolitan Administration
BMR	Bangkok Metropolitan Region
BRT	Bus Rapid Transit
BTS	Bangkok Mass Transit System
CA	Cellular Automata
CBD	Central Business District
GPS	Global Positioning System
HCM	Highway Capacity Manual
HIS	Hue, Saturation, Intensity
HOV	High-Occupancy Vehicle
LADAR	Laser Detection And Ranging
LHS	Latin Hypercube Sampling
LIDAR	Light Detection And Ranging
LOS	Level of Service
MRT	Mass Rapid Transit
MRTA	Mass Rapid Transit Authority of Thailand
MSE	Mean Squared Error
NFPA	National Fire Protection Association
NIST	National Institute of Standards and Technology

OD	Origin and Destination
PTV	Planung Transport Verkehr
RGB	Red Blue Green
RMSP	Root Mean Square Percentage
SE	Square error
SFM	Social Force Model
SSE	Sum Squire Error
VISSIM	Verkehr In Städten – SIMulationsmodell



CHAPTER 1

INTRODUCTION

1.1 General

In Thailand, the railway system was a very popular method of transportation. This is because it allows for a more efficient form of transportation, does not have congestion when traveling, which are problems that commuters and travelers often face in other forms of transportation, such as road vehicles. There is the capability to reach the proximity of any location within the urban areas with minimal limitations. It could reach the dense areas of the city center or past the underground or underwater passages, without having to account for traffic situations, safety or other nuances. Lastly, this method of transportation is highly reliable in most cases. Railway transportation as a mode of transport is often more reliable than the other modes of transportation, in several criteria. First and foremost, railway transits will depart from a location and arrive at a destination within the expected time with often minimal delays. Accidents are less prone to occur, and the cost always remain constant, regardless of the date and time. Currently, railway systems in Bangkok are classified into 3 categories. The first category is the Bangkok Mass Transit System (BTS), which carries the distinctive widespread name amongst Thai locals as the 'sky train'. The system mainly consists of stations inside Bangkok. The second category is the Metropolitan Rapid Transit (MRT), which contains both the underground train and the elevated railways above Bangkok's roads. The organization has constructed stations both inside and outside of Bangkok. The third category is the Airport Rail Link (ARL), which is an elevated railway connecting between Suvarnabhumi airport and Bangkok's Central Business District. More than 2 million people commute through its train station per day. The areas in the country where there are high density and concentration of walking humans are called "Pedestrian flow areas". A study is required to be initiated which analyzes human movement patterns. In global, the studies of the pedestrian flow were concluded and analyzed regularly with updates. It is useful and practical for researchers to understand the pattern of human movement. This study can develop and aid Thailand's

infrastructure in diverse ways, and the knowledge gained can be useful for any related studies that may be conducted in the future.



Figure 1.1 Passenger in Railway Station

1.2 Background of the study

In the past, Thailand did not have severe problems with congestion because the number of cars and related vehicles are not high. Bangkok is one of the cities with highest congestion problems in the world. The cause of congestion is derived from the lack of high-quality management of land use (Sisoutham & Piantanakulchai, 2018), which includes public transportation. Therefore, people find that using a personal vehicle is more efficient for their daily needs. This is based on statistics of the number of personal vehicles (car and motorcycle) registered in the country, which increases consistently each year from 2008 – 2017 (MRTA, 2018)

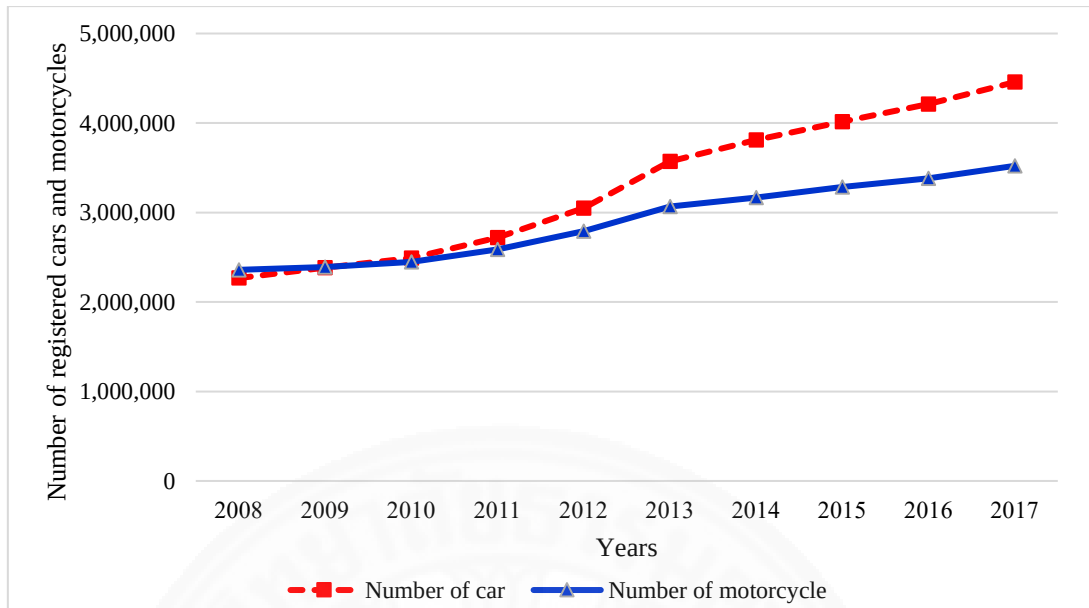


Figure 1.2 Number of Car and Motorcycle in Bangkok
Source: (MRTA, 2018)

While the number of public bus users decreased consistently during the same time period.

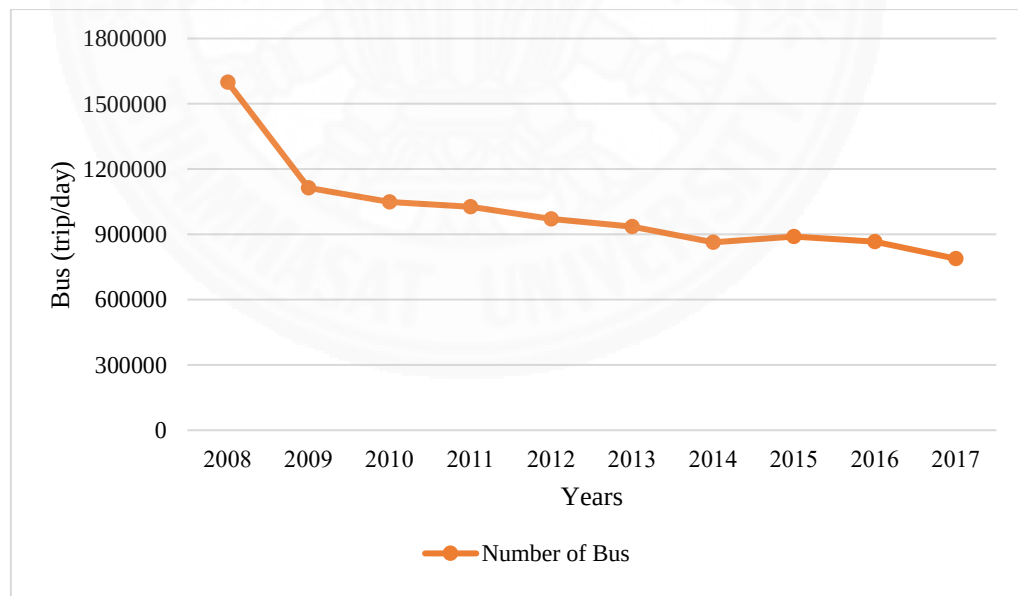


Figure 1.3 Number of people using a bus in Bangkok
Source: (MRTA, 2018)

In various public places, such as mass transit railway stations, Thousands of pedestrians move through the stations each day. Each person that travels using the mass

railway transit may have different objectives while passing through the designated areas, but there are usually definitive patterns that occur when all the pedestrians and their actions are incorporated together and analyzed. The theory behind analyzing pedestrians' movement patterns is a key issue in the past and currently remains a key issue. This issue remains a task to accomplish in many developing nations. There are some researches documenting many aspects regarding pedestrians and their actions in public places. The places included public train stations. However, this is an unexplored subject in Thailand. Information regarding pedestrians in Thailand is currently not sufficient. This issue initiates the motivation of this study. Thailand have the possibility of pedestrian behaviors, which can be different when the data is compared with other countries. The information gathered will be a practical advantage to many industries located within and outside the country. The information could be useful to development projects concerning structures, infrastructure, and systems currently being undertaken or planning to be deployed in the future. The data of pedestrian movement provided the advantages in term of safety of pedestrian in train stations and planning to handle the growth of population and the efficiency of operating a new station.

This research focuses on the underground train (MRT), a system of railway transportation pathways that travel through the Bangkok Metropolis, and is operated by the Mass Railway Transit Authority of Thailand (MRTA). Currently, the service offers two operating lines. The first line to start its operation is the Chaloem Ratchamonkhon (The Blue Line,) in 2004. The other line is the Chalong Ratchadham (The Purple Line,) began enabling pedestrian usage in 2016. The Blue Line measures a total path of 21 kilometers, with 19 stations in operation. The Purple Line contains 23 kilometers of travel path, with 16 operating stations.

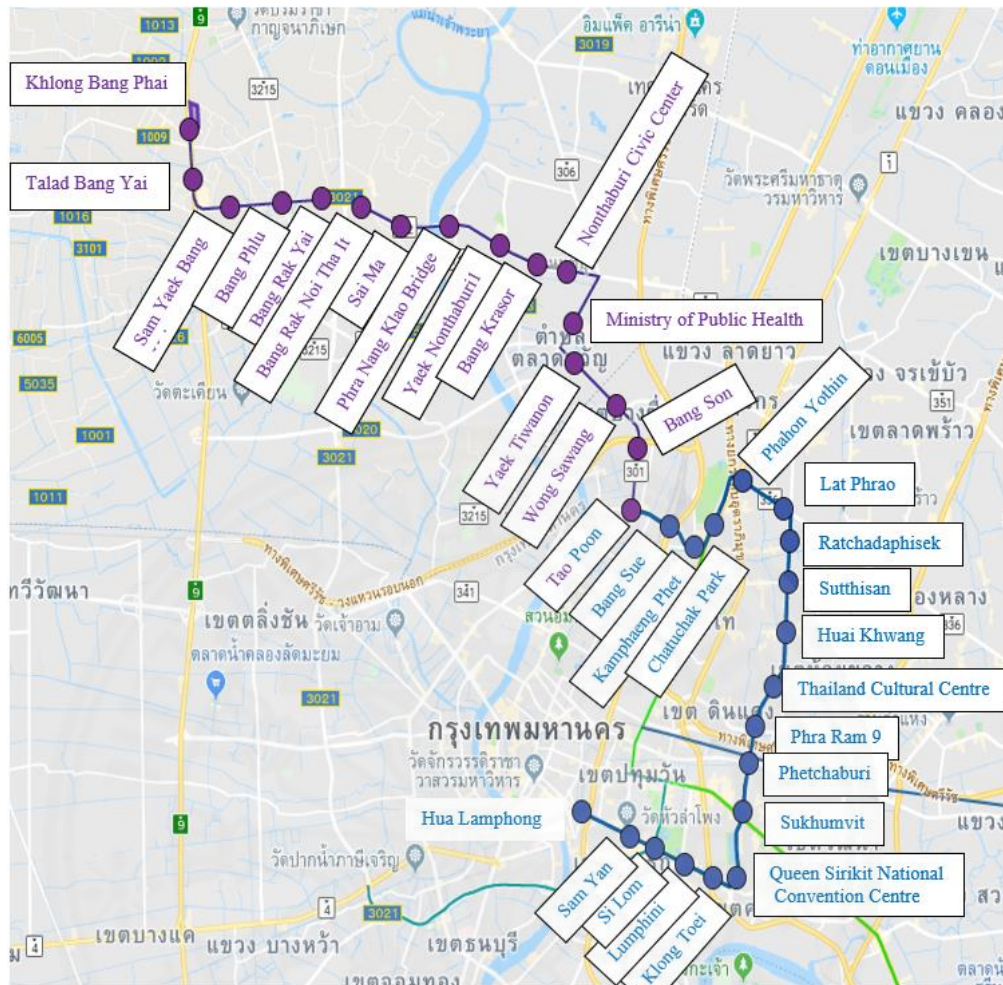


Figure 1.4 MRT Blue Line and Purple Line stations

1.3 Statement of the problem

Railway transportation is one of the most critical modes for people who want to travel in Bangkok. The proportion of people using different transportation modes in Bangkok shows that the most attractive systems for travelers are BTS Skytrain (37.1%) followed by bus and van (34.52%) (MRTA, 2018). Figure 1.5 shows that railway transportation has the most proportion of people using in Bangkok with the percentage out of all travelers approximately 54.67 % including sky train (BTS), underground train (MRT) and airport rail link (ARL). The Mass Rapid Transit (MRT) has planned to cover railways in the Bangkok Metropolitan Region (BMR) by expanding their station count. Therefore, to simulate the pedestrian flow when a new station is being developed.

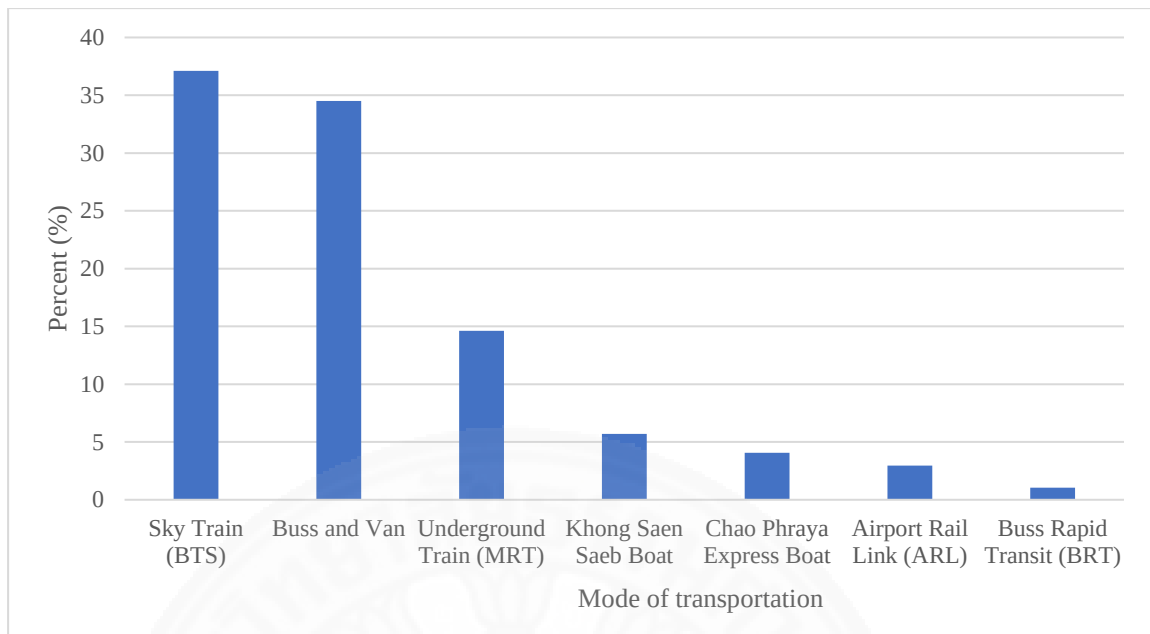


Figure1.5 Proportion of public transportation in Bangkok
Source: (MRTA, 2018)

Therefore, the study about pedestrian flow should be the topic to input in the simulation model. In addition, pedestrian behavior represents the necessary data including numbers of pedestrian, pedestrian route, speed of pedestrian, travel time and etc. The challenges are how to make the model reliable. Correct parameters in simulation can make the model realistic.

The calibration of parameter is the most important process to ensure that the model is reliable in the real world. Some software, such as VISSIM provide the default parameters for pedestrian behavior in Germany. In Thailand, number of studies providing calibrated parameters in pedestrian simulation is limited. This thesis focuses on the calibration of parameters in pedestrian simulation in train stations in Thailand. The calibrated model was used to simulate the pedestrian flow in train stations in Thailand.

1.4 Significance of the study

This study calibrated the parameters to adjust the walking behaviors in the train stations. In addition, this study the evacuation of pedestrians in the train stations simulated evacuation time between the simulation model and the standard from

National Fire Protection Association (NFPA)130 and the Ministry of Interior Regulations in Thailand were compared. This study focus on the parameters representing walking behaviors in train stations in Thailand, it will be necessary information to increase the reliability of the model. In the future, the studies about pedestrian flow in train stations will be critical due to the increase of people and users using railway transportation.

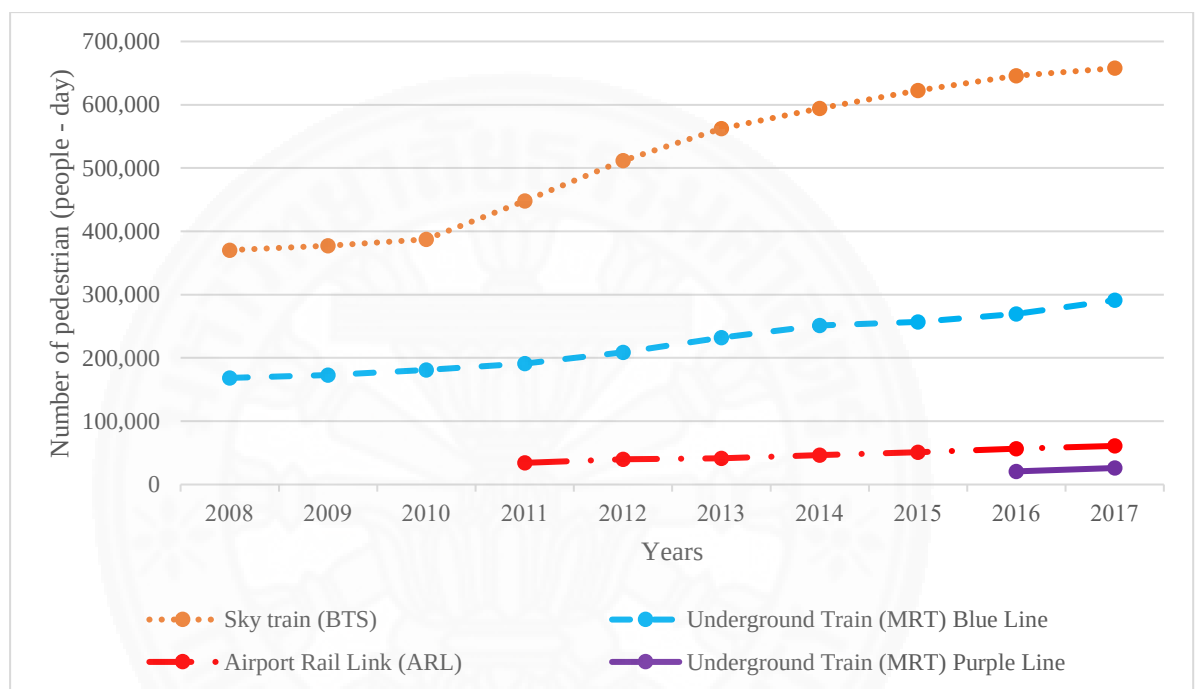


Figure1.6 The average number of passengers in an urban railway in Bangkok

Source: (MRTA, 2018)

In addition, the number of passengers of the MRT blue line is gradually increasing from around 170,000 trips/day in 2008 to 290,000 trips/day in 2017 (Figure 1.6), 6.3% average growth per year. At this growth rate, ridership of the MRT blue line will reach about 450,000 trips/day in 2025 and 530,000 trips/day in 2030.

Furthermore, some parameters can be changed in the future due to the changing behavior of people, which is unpredictable and subject to external factors. This study will be a guideline for those who wish to develop pedestrian parameters in models to be more reliable.

1.5 Purpose of the study

The objective of this research is to simulate and identify the walking behavior of the pedestrian in train station. Thus, the calibration process showed the detail of each parameter to each situation and evaluation is conducted using microscopic elements to find the ideal setting for different scenarios. The purposes of this study are the following:

- To review parameters used in pedestrian simulation in the literature
- Calibrate and validate the parameters to represent the pedestrian behaviors in Thailand
- Apply calibrated parameters for pedestrian evacuation in a case study in a train station in Bangkok, Thailand

1.6 Scope of the study

The study area of this research is the MRT Huai Khwang station on Ratchadaphisek road, one of the MRT blue line stations. PPD (2012) revealed that MRT Huai Kwang station is one of the four stations with the highest number of passengers, due to its location in a densely populated residential area. The aim is to study the human movement in the train station. This was done by observing and recording video cameras in the morning hours (7.30 am – 8.30 am) in order to evaluate the pedestrian flow and input it into the simulation model.

PTV VISWALK software was used to create the model of pedestrian flow in train stations. Calibration is taking into account to ensure the model will be more reliable and the simulation should represent the walking behavior of pedestrians as close to actual situations as possible. After finding the suitable values of each parameter, the data were applied in a case study to validate the parameters which represent walking behaviors in the train station in Thailand.

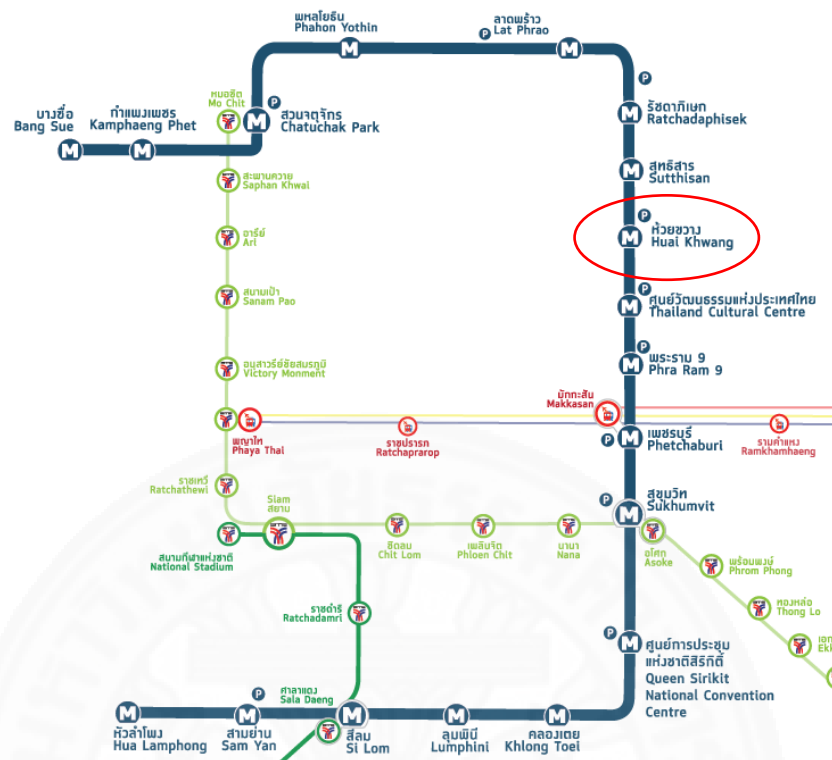


Figure1.7 The location of MRT Huai Khwang station

Source: (MRTA, 2018)

CHAPTER 2

LITERATURE REVIEW

2.1 Pedestrian flow

The pedestrian flow is the movement of humans that also includes the pattern of walking in a specific area. The growth of the population became a problem in terms of congestion and affects the transportation problem (Caramuta et al., 2017). The study of pedestrian flow is being conducted worldwide to handle the growth of the population and accommodate the people. This prompts researchers to develop the study of human walking to control the flow of the people.



Figure 2.1 The congestion of pedestrian in train station in Bangkok

Pedestrian flow at a train station studies humans walking in train stations and tries to recreate the pattern of humans in each area of study. Pedestrian flow characteristics are influenced by age, gender, luggage carried, and additional information such as space availability. The walking speed of each constraint is compared (Zhao & Liang, 2016). The fluctuation of pedestrian flow depends on the

time of train arrival and departure. Expectedly in peak hours, there is a large passenger flow. Most of the researchers select the study area in transit stations because there are many pedestrians in this area and using a video camera to set up in each area, it becomes easy to observe the movement of pedestrians to create the original and destination (OD) of pedestrians.

The reasons why researchers study pedestrian flow and place it as a very critical topic include the problems created by humans. The problems are more evident in densely populated developing nations. The problem occurs because it is impossible to control a large number of people when they enter a mass transit railway station. The number of people that enter and exit a mass transit railway station will increase as time progresses. The crowd of pedestrians travel in all directions and the congestion will occur. When there is an irregularly high amount of commuters in the stations, it can result in an excess of the capacity of stations. This results in long waiting queues around the platform, as well as overcrowding, where pedestrians experience uncomfortable sensations in all directions due to the high pedestrian density. A. L. Lu, Ren, Wang, and Chan (2015) stated that when the researchers attempted to decrease the time spent on pedestrian crosswalks, they observed human behavior in that area. The pedestrian warrant and standard should be considered when a pedestrian's facility needs to be constructed by comparing the observations (Prabhu & Sarkar, 2016). Facilities were designed for comfort of people and solving the pedestrian traffic in some areas by using calculated factors such as maximum capacity, proper location, and level of service.

In the train station, there are many causes and problems needed to study pedestrian flow, such as the long queues, as well as the congestion at the platform. Therefore, many researchers attempt to study this pattern. Zhao and Liang (2016) stated three typical metro stations were chosen to measure the data by finding the relation between moving speed and the person's individual information. The researcher wants to obtain and analyze the gathered data. For understanding the pedestrian flow, they measured generation or attraction of traffic and traffic of each link. Therefore, they can create the OD matrix to see the pattern of movement (Ahn, Kowada, Tsukaguchi, & Vandebona, 2017). Some researchers study the pedestrian flow, due to validate their hypothesis. Kasperski (2017) stated that when the flow became denser, the slower person forces the faster person to reduce their walking speed and the faster person

leading the slower person adjusts their speed. Transit stations are the popular place to study pedestrians. Some short periods where there is pedestrian fluctuation is necessary for collecting data, as the problem was seen at this period. At a normal time for waiting for train station, the people stay at different locations but when the train arrives, people move to the point that the train stops to board the train. Once the train's door opens, the crowd of people tries to move in or move out of the train and the congestion occurs at this point (Seriani & Fernandez, 2015).

Pedestrian flow was studied in a general case such as the analysis in the canteen during peak hours (Tang, Zhang, Zhang, & Wang, 2019). Due to peak hours, the results showed a high number of students and a higher queueing time, so the management of the pedestrian flow problem in the canteen was considered to decrease the congestion and queueing time in real situations. Qiu, Song, He, and Yin (2018) studied the effects of Y-shaped channel to pedestrian flow, the congestion occurred at the connection of the Y channel and the angle affects the flow density. A macroscopic model was studied about the interaction between vehicle traffic and pedestrian flow (Borsche & Meurer, 2019). Furthermore, the specific case of pedestrian flow was conducted by controlled experiments for crowd management and public safety under different densities (P. Wang, Cao, & Yao, 2019). In addition, the experiment came from the bottleneck which is a general problem in narrow spaces. The study showed the relationship between density and speed time (Liao et al., 2016). In the evacuation of a disaster, the infrastructure collapsed during the earthquake situation. Therefore, the falling of debris is a serious issue of safety in the simulation (X. Lu, Yang, Cimellaro, & Xu, 2019). However, the important factor should be evaluated in the experiment, following emotional state, the scope of study and realism in the experiment.

The evacuation is the process of emergency response to manage a crowd of people for the safety of evacuees during emergency circumstances. The parameters that affect pedestrian evacuation in most cases are structural design and evacuation behaviors. Some examples of previous research analyzed and classified the parameters following the structure designed (Hoel & Rozner, 1976), emotional states (Mao, Du, Li, & He, 2019), flames with high temperature (Y. Li, Wang, Wang, & Huang, 2017) and smoke or limit of visibility (Chen et al., 2019; P. Wang & Cao, 2019). The speed

of evacuees during an evacuation is not higher than the normal walking speed due to high density during emergency situations (Shi et al., 2012).

2.1.1 The pedestrians' studies in Thailand

The walking behavior in Thailand has been studied in a few research projects. In this research project, the results found that the distance to the transportation terminal that would determine whether the person walked or drove, for example, is approximately 300 - 400 meters. The satisfaction of each individual to the walkways is usually in the middle range of the previous approximation. Due to the convenience levels and the safety levels are low in Thailand when compared to the levels of other countries. Other problems include how narrow or small the width of the walkway, the unsatisfactory condition of the path and the obstruction and the objects that are in the way, resulting in the walker having to diverge around, or needing to move into dangerous traffic areas. For the speed of the pedestrians, the study concluded their results in the table below (Sangsila, 2012)

Table 2.1 Pedestrian walking speed

The type of pedestrians	Velocity (km/hr.)
General pedestrian	4.32
Elderly	4.02
Groups of pedestrian	3.06
Descending stairs	2.76
Ascending stairs	2.04

Source: (Sangsila, 2012)

From the above Table 2.1, it showed the pedestrian walking speed that accesses to the train station. In particular, the Western hemisphere and their drivers usually give higher priorities to pedestrians when on the road. The Western hemisphere on average has more developed transit systems and terminals. This persuades the average pedestrian, resulting in public transportation seeming more attractive. These places tend to build properly developed road systems, footpaths, and sidewalks.

In the railway system, the study of pedestrians in the underground train station was conducted to develop a model to present walking behavior, including the number of pedestrians, pedestrian routes, pedestrian speed and facilities (MRTA, 2016). In the model analysis and evaluation, the results showed pedestrian travel time in the station from point to point and also evaluated the facilities with service time and queueing time of passengers. The objective of this report is to compare the simulation with the actual situation, evaluating how realistic the simulation is. However, pedestrian analysis has not yet been conducted in Thailand, such as parameters or pedestrian behaviors.

Moreover, there are previous studies about fire safety engineering, studying about fire prevention techniques and flame related evacuation. There was also the design of the exit door width and its effects on evacuation. The results showed large exit door size will result in less evacuation time and that the smoke detector does not effect evacuation (Saelao, 2001) From the study of fire protection system in a hospital using National Fire Protect Association (NFPA) and Ministry of Interior Relations, it was found that some problems in the fire protection system occurred due to the lack of monitoring (Sukkiwanut, 2011).

2.1.2 Data collection methods

The methods to collect the data are varied because different researchers use different techniques to collect information, popular techniques include observation. This method is the most convenient way to collect pedestrian data or moving data because the data collector is able to notice the person and count them easily. In the present, the researchers are developing technology to collect data such as GPS data, laser, video camera, infrared, sensors with the aim of pedestrian detection. But pedestrian behavior is unpredictable and depends on the current situation when observing. Caramuta et al. (2017) stated that the techniques will develop each year and new techniques have been carrying out the innovation concept and resulting in the increase of automation. The methods that used to find pedestrian data are as follows:

- Manual counting (Caramuta et al., 2017)

This method is the most convenient to conduct. It may include tools such as the pen, paper or applications in the smartphone to count. Generally, manual counts are

conducted by one person standing on the surveying location and set the line to count pedestrians passing over the line in each direction. Accuracy depended on the amount of pedestrians, influencing the visibility of the surveyor.

The advantages of this technique are the quick setups and low cost. However, it can also be influenced by weather conditions.

- Video recording (Caramuta et al., 2017)

Video Image Processing has gathered the interest of researchers due to the opportunity of detecting multiple lanes and zone a large amount of information. However, data was collected in video recording output by multiple files, it is unable to be used directly. Therefore, some studies use artificial intelligence (AI) to detect people and count as numbers and obtain as data.

The advantages of this technology include it being ease of installation and may be accurately controlled over large areas, and provides wider analysis. Disadvantages include that the data obtained cannot be directly used, the errors of data file which may happen in some tests and the possibility of suffering from environmental changes.

- RGB or HIS cameras (Caramuta et al., 2017)

RGB space is used to acquire and elaborate images. HIS (Hue, Saturation, Intensity) space provides color with human color perception. This method obtains data in the form of pedestrian numbers and trajectory. This allows creating the database following travel time and tracking of pedestrians.

The advantages of this method is the related to the technology. It can be imported into Matlab, and the cameras contain three sensors to detect the three color components.

- Laser (Caramuta et al., 2017)

Previously, known by the name of LIDAR(Light Detection And Ranging) or LADAR (Laser Detection And Ranging). This technology uses laser beams to measure the distance of objects and detect pedestrians or vehicles. Moreover, it can measure the speed, size of the object and tracks their trajectory following with two scanners, one vertical and one horizontal.

The advantages of laser technology are that it can collect large amounts of information in a short period of time and the method works under any weather

conditions. However, it cannot classify the characteristics of pedestrians and the technology requires large amounts of electrical energy to operate.

- GPS data (Caramuta et al., 2017)

GPS sensors are used to measure the speed, route of the pedestrian, delay, flow, preferred time and travel time. The application is restricted to buildings and places which electronic device can be used to track pedestrians.

The popular methods for researchers are observation and setting up a video camera in the area of interest. Once the video camera is set up, the time to collect the data is selected and the data is obtained by observing video files. The data to collect is the number of pedestrians, and different types of luggage they carry. (Patra, Sala, & Ravishankar, 2017; Zhao & Liang, 2016; Zhao, Yan, Liang, & Ye, 2014). Shah, Joshi, and Parida (2013) stated that to study about the decision of pedestrians is to use different facilities inside the railway station. Observation or Manual counting is the simplest way to do surveys. However, a small scope of work is selected because the accuracy is limited when compared with setting the video camera (Kasperski, 2017; A. L. Lu et al., 2015; Prabhu & Sarkar, 2016). Currently, the developing of technology resulted a new method to collect data using artificial intelligence (AI). In order to track the pedestrian flow in video recording, AI is mainly used to count the pedestrian and create trajectories (Cui, Zhang, He, & Hu, 2019). For the pedestrian analysis method, after receiving sufficient data, the researcher can use the information directly, such as the number of passages and the movement of pedestrians. The methods indirectly use the data including information obtained from video cameras, measuring the speed of pedestrians in relation to the passage. When researchers obtain the large amounts of data, they have many methods available in which to analyze the data. Some people classify the data in each category such as age, gender or type of shoes (Shah et al., 2013).

2.1.3 Pedestrian facilities design method

The information and data that is needed in order to analyze and design the structures that will be used to carry pedestrians and people. These include roads, sidewalks, and buildings. Jotin and Kent (2003) stated that the data of pedestrians used

to design the facility is based on the design of level of service and location of each facility, the pedestrian design includes the following (HCM, 2000):

- Human space requirements

The individual person requires a minimum space area of 2.3 ft²/person but the area is not suitable for human beings which are carrying luggage. If the human is carrying extra luggage, the suggested area changes to requiring about 7 to 10 ft²/person

- Pedestrian speed – density – flow relationship

For the pedestrian study, this is the explanation of the pedestrian

- Pedestrian speed: average walking speed
- Pedestrian flow rate: number of pedestrians passing a point per unit time
- Unit with flow: pedestrians per minute per ft.
- Platoon: a number of pedestrian walking together in a group
- Pedestrian density: average number of pedestrians per unit area
- Pedestrian space: average area provided for each pedestrian

These formula are used to find pedestrian flow:

$$V = S \times D \quad (1)$$

Where V = Pedestrian flow in ped/min/ft
 S = Pedestrian speed in ft/min
 D = Pedestrian density in ped/ft

$$\text{Or} \quad V = S/M \quad (2)$$

Where M = Pedestrian module in ft²/ped

Relationship between pedestrian speed and density

$$V = \frac{v}{15W} \quad (3)$$

Where v = Peak pedestrian flow (ped/15 min)
 W = Effective walkway width (ft)

- Effective walkway width (A. L. Lu et al., 2015)

The concept of this showed that the walkway width can affect the mobile pedestrian. Normally, pedestrians passing each other require about 2.5 ft width of space to freely pass without uncomfortable sensations. The width which can effectively be used by each pedestrian is called “the clear walkway width.”

- Walking speed

Many researchers find the effects of walking speed to include land use, age, gender, and environment factor. The speed of pedestrians depends on the spacing area, current situation and the difference between peoples' characteristics.

- Planning for pedestrian

The influence of factors to design elements for pedestrian is the demand of people, safety and the space required. Pedestrian demand consists of estimating traffic volumes, traffic pattern, and composition.

- Level of Service Criteria for Walking

Space can measure the pedestrian facility design, which is normally taken to be 25 ped/min/ft. Fluctuations can occur in the short-term for the train station, especially when trains arrive and depart. Level of service (LOS) was classified by the density of people in area per minute.

Table 2.2 Average flow LOS criteria for walkway and sidewalk

Level of Service	Space (ft ² /ped)	Flow Rate (ped/min/ft)	Speed (ft/sec)	v/c Ratio
A	> 60	≤ 5	> 4.25	≤ 0.21
B	> 40-60	> 5-7	> 4.17-4.25	> 0.21-0.31
C	> 24-60	> 7-10	> 4.00-4.17	> 0.31-0.44
D	> 15-24	> 10-15	> 3.75-4.00	> 0.44-0.65
E	> 8-15	> 15-23	> 2.50-3.75	> 0.65-1.0
F	≤ 8	Variable	≤ 2.50	Variable

Source: (HCM, 2000)

LOS A

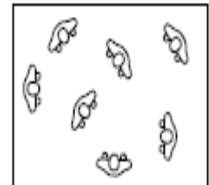
Average Pedestrian Space $> 1.2 \text{ m}^2/\text{p}$

Standing and free circulation through the queuing area is possible without disturbing others within the queue.

**LOS B**

Average Pedestrian Space $> 0.9\text{--}1.2 \text{ m}^2/\text{p}$

Standing and partially restricted circulation to avoid disturbing others in the queue is possible.

**LOS C**

Average Pedestrian Space $> 0.6\text{--}0.9 \text{ m}^2/\text{p}$

Standing and restricted circulation through the queuing area by disturbing others in the queue is possible; this density is within the range of personal comfort.

**LOS D**

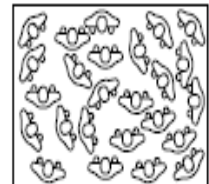
Average Pedestrian Space $> 0.3\text{--}0.6 \text{ m}^2/\text{p}$

Standing without touching is possible; circulation is severely restricted within the queue and forward movement is only possible as a group; long-term waiting at this density is uncomfortable.

**LOS E**

Average Pedestrian Space $> 0.2\text{--}0.3 \text{ m}^2/\text{p}$

Standing in physical contact with others is unavoidable; circulation in the queue is not possible; queuing can only be sustained for a short period without serious discomfort.

**LOS F**

Average Pedestrian Space $\leq 0.2 \text{ m}^2/\text{p}$

Virtually all persons within the queue are standing in direct physical contact with others; this density is extremely uncomfortable; no movement is possible in the queue; there is potential for panic in large crowds at this density.

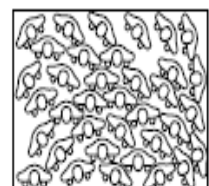


Figure 2.2 Queue area level of service

Source: (HCM, 2000)

LOS A

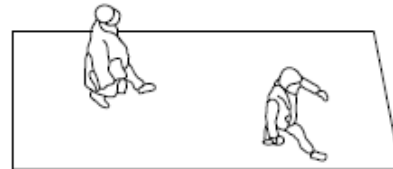
Pedestrian Space > 5.6 m²/p *Flow Rate* ≤ 16 p/min/m

At a walkway LOS A, pedestrians move in desired paths without altering their movements in response to other pedestrians. Walking speeds are freely selected, and conflicts between pedestrians are unlikely.

**LOS B**

Pedestrian Space > 3.7–5.6 m²/p *Flow Rate* > 16–23 p/min/m

At LOS B, there is sufficient area for pedestrians to select walking speeds freely, to bypass other pedestrians, and to avoid crossing conflicts. At this level, pedestrians begin to be aware of other pedestrians, and to respond to their presence when selecting a walking path.

**LOS C**

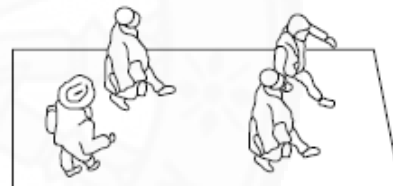
Pedestrian Space > 2.2–3.7 m²/p *Flow Rate* > 23–33 p/min/m

At LOS C, space is sufficient for normal walking speeds, and for bypassing other pedestrians in primarily unidirectional streams. Reverse-direction or crossing movements can cause minor conflicts, and speeds and flow rate are somewhat lower.

**LOS D**

Pedestrian Space > 1.4–2.2 m²/p *Flow Rate* > 33–49 p/min/m

At LOS D, freedom to select individual walking speed and to bypass other pedestrians is restricted. Crossing or reverse-flow movements face a high probability of conflict, requiring frequent changes in speed and position. The LOS provides reasonably fluid flow, but friction and interaction between pedestrians is likely.

**LOS E**

Pedestrian Space > 0.75–1.4 m²/p *Flow Rate* > 49–75 p/min/m

At LOS E, virtually all pedestrians restrict their normal walking speed, frequently adjusting their gait. At the lower range, forward movement is possible only by shuffling. Space is not sufficient for passing slower pedestrians. Cross- or reverse-flow movements are possible only with extreme difficulties. Design volumes approach the limit of walkway capacity, with stoppages and interruptions to flow.

**LOS F**

Pedestrian Space ≤ 0.75 m²/p *Flow Rate* varies p/min/m

At LOS F, all walking speeds are severely restricted, and forward progress is made only by shuffling. There is frequent, unavoidable contact with other pedestrians. Cross- and reverse-flow movements are virtually impossible. Flow is sporadic and unstable. Space is more characteristic of queued pedestrians than of moving pedestrian streams.



Figure 2.3 Pedestrian walkway level of service

Source: (HCM, 2000)

- Environment factor

The following factors should be considered in designing pedestrian facility:

- Comfort: skywalk
- Convenience: walking distance
- Safety: traffic control devices
- Security: line of sight and light
- Economic: minimization of travel delays

2.2 Pedestrian simulation

Simulation is the representation of behavior and characteristics of one system through the use of another virtual system, such as by a computer program designed for the purpose. Before the simulation process, the first requirement is to develop a model of study. One of the advantages of simulations is providing users to predict the correctness and efficiency of the model. It is a tool for helping the researcher to transfer data to the system and simulate the idea to communicate with other people. In the Civil Engineering field, simulation is taken into account to evaluate the structure design and operation of the building and its effect on users.

In the present, simulation programs have various software classified by the function of the model. In order to represent a realistic scenario of each situation such as rush hour, evacuation and transition of the passenger. Therefore, each model has a software suitable. Mihailovs, Sansyzbajeva, and Meztis (2017) stated that the data from the past of several years is needed to forecast optimal plans for transportation. Some studies use simulations to simulate the problem and find a method to solve the problem. Ahn et al. (2017) stated that developing the method to decrease congestion is needed when setting a new platform in the railway station. Currently, technology is necessary for researchers because it can help them conduct research with more ease than in the past.

Pedestrian flow simulation is the simulation of the human movement patterns to find the behavior of humans by using the software of simulations. The researchers developed model to explain and solve the problem, such as researching the effects of certain setup when operating a new platform and problems such as pedestrian flow (Ahn

et al., 2017). A final goal can be in the form such as to decrease the congestion of the main road. For example, researchers are unsure whether crosswalks will decrease pedestrian congestion. Therefore, a simulation should be created to find the result of the proposed solution, to estimate the clearance time of each routing to finding the minimize total evacuation time (Lee & Tseng, 2014). The constraints and parameters were considered in each scenario of the model to virtualize the real situation in simulation according to real-world data. Tong and Cheng (2013) stated that they simulate the pedestrian moving from a large room with inner barriers and four exits to find the trend of evacuation times with respect to the impact factor of pedestrian and shape of the exits. In addition, the simulation model can be applied worldwide in case of evacuation when an evacuation plan is needed. Thus, simulation programs are used to simulate under different scenarios, such as evacuation with fire and smoke (Y. Li et al., 2017). Some researchers developed an evacuation model for fire safety engineering and provided new approaches that they claim to be useful for future structures (Ronchi et al., 2019).

The important factors to consider in the simulation process are the model following the social force model, microscopic model, queueing model, etc.

2.2.1 Modeling pedestrian dynamics

The model of pedestrians is highly dependent on the study of pedestrian dynamics (Caramuta et al., 2017). The scope of the study should be related to models such as the macroscopic model used to evacuate the traffic flow of pedestrians and vehicles. Generally, most of study combined the model to validate different scenarios in pedestrian flow. There are also other models about pedestrian study, as following:

- Social force model

Social force model is considered the representative of pedestrian dynamics, interaction between pedestrians and effects of the environment. It takes into account not only the physical, but also psychological interactions among individuals (Kang, Zhang, & Li, 2019). The social force model is the most popular model used to describe the movement of pedestrians with simple mathematical formulation (Ma et al., 2019).

The general equation of the social force was written as a sum of different attractive and repulsive effects (Helbing & Johansson, 2009):

$$\vec{f}_i(t) = m_i \frac{d\vec{v}_i}{dt} = m_i \frac{v_i^o(t)\vec{e}_i^o - \vec{v}_i(t)}{\tau_j} + \sum_{j(\neq i)} \vec{f}_{ij} + \sum_w \vec{f}_{iw} \quad (4)$$

Where $\vec{f}_i(t)$ = the individual's total motivation to move in a certain direction at a specific time (t).

m_i = the mass of the individual.

$v_i^o(t)\vec{e}_i^o$ = a pedestrian movement with a certain speed and certain direction.

$\vec{v}_i(t)$ = a current velocity of a pedestrian.

τ_j = relaxation time.

$\vec{f}_{ij}$ = the repulsive force of pedestrian

$\vec{f}_{iw}$ = the repulsive force of the wall.

In case of a rail transit station, there is also a fluctuation term to account the deviation on social force model (Helbing & Molnar, 1995), which is occurred on the train arrival and departure:

$$\frac{d\vec{w}}{dt} = \vec{f}_i(t) + \text{fluctuations} \quad (5)$$

Previously, the social force model was mainly focused on the evacuation of buildings with the goal of pedestrians selected to reach the exit as fast as possible (Johansson, Peterson, & Tapani, 2015). For example, using this model to evaluate the emergency earthquake situations by classifying the pedestrians into lower to higher density (Zhang, Liu, Qin, & Liu, 2018). The researcher developed the social force model to apply to studies and cases worldwide such as methods to guide pedestrians to the exit safely (Yang, Dong, Wang, Chen, & Hu, 2014), evacuation under terrorist attack (Liu, 2018) and validate by comparing with real world monitoring (Seer, Rudloff, Matyus, & Brändle, 2014).

Moreover, the social force model is often used in pedestrian studies because it could be explained as a mathematic model and be adapted to different studies. However, the method cannot be used in cases such as the queue model. For more reliable results, another model should be used in this case.

- Microscopic model

The microscopic model describes the pedestrian movement, starting from the smallest entity or sample that is representable, either one pedestrian in a group or a crowd. They treat the person as an individual ‘agent’ who takes up a certain location or space in an instant period of time (Caramuta et al., 2017). The data useful for this model cannot be interchangeable with other kinds of approaches. To guarantee the suitability of the microscopic model to be used with every general case, a statistical calibration must be done. That means it is necessary that every individual movement data must be measured. W. Wang, Lo, Liu, and Kuang (2014) used the microscopic model to analyze pedestrian movement behavior in shopping malls. In order to determine the factor effect on behavior and evaluate the parameter in simulation model. The microscopic model is not only used in pedestrian studies but also applies in traffic situations (vehicle).

- Cellular automata model

The cellular automata model described the walking of a single pedestrian according to the cell occupancy that is based on time in the simulation approach and a regular grid cell (Caramuta et al., 2017). In addition, the needed requirement in this model includes the origin and destination (OD), pedestrian speed and density. Hu, You, Zhang, Wei, and Guo (2018) studied queueing behaviors in the evacuation by using the CA model to describe the pattern of evacuation and effect of queueing to evacuees. The CA model is simple and easy to simulate in computer programs based on the characteristics of pedestrians and the surrounding environment (X. Li, Geng, Kuang, Bai, & Fan, 2019). Blue and Adler (2001) proposed the CA model for providing three simulation models of bi-direction flow, which made the CA model widely used in pedestrian studies.

- Queueing model

The queueing model simulation is based on certain discrete events. This happens as each pedestrian is modeled and represented as a single flow object, and this object interacts with other things of the same kind or other dissimilar objects, while facilities are represented as a network which is made up of arches and nodes. These kinds of models have been developed to study evacuation dynamics (Caramuta et al., 2017).

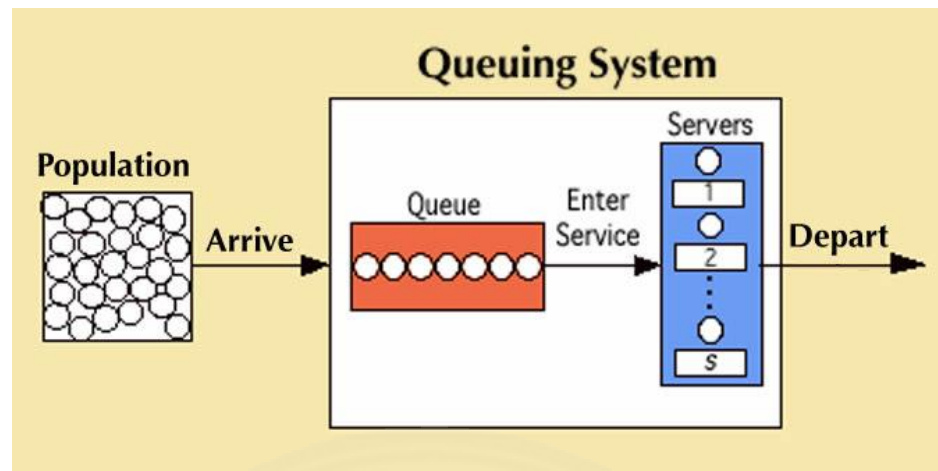


Figure 2.4 Queueing model

Yanagisawa et al. (2013) used queueing model to study the effect of delay in walking from the head of a queue service and obtain a suitable type of queueing system under various conditions.

2.2.2 Pedestrian simulation software

There are many types of software that were used in the pedestrian simulation. Each software has different abilities and limitations. Therefore, selecting the appropriate software for specific objectives is very critical. Caramuta et al. (2017) stated that the process to select the most appropriate software is classified into four steps. The first step considered the characteristics and requirements of each software, with each outstanding in a situation. The second step researched software and determined the function and potential of the software. The third step compares the software to find the most suitable for the study and computer benchmarks. The final step is the results obtained from simulation, where researchers evaluate whether the data responded in expected results. Some examples of pedestrian simulation software include as follows;

- PTV VISWALK

VISWALK is a commercial software developed by PTV group. It is implemented by the social force model and simulation running in the planning of buildings, evacuation, and transit in mode of transportation (Caramuta et al., 2017;

Dubroca-Voisin, Kabalan, & Leurent, 2019). Ahn et al. (2017) provided a future for operation new adding platform after simulation revealed that congestion occurs when pedestrian flow crosses between the new platform and current platform. Walking behavior is the one requirement needed to input into the VISWALK software according to the social force model. This software is able to generate characteristics of a pedestrian (man, woman and wheelchair) and vehicle type (car, bus and train).

VISWALK and its inputs require the attributes area (level and function), pedestrian input (number of pedestrian and location), and pedestrian route (origin and destination). Outputs can display the results following data such as density, pedestrian speed, area measurement, time waiting queue, delay on service and table or chart.

- Mass Motion

Mass Motion is a pedestrian simulation developed by Oasys Limited and consisted of two different models, the social force model and best-effort ones (Caramuta et al., 2017). The desired speed depends on the type of distribution (uniform, normal and triangular) and density, there is a factor that affects the desired speed such as obstacles on the path and ramp or elevator. Moreover, Mass Motion is permitted to change the default value due to being more realistic in simulation. The output in this software shows the number of frames and identification of pedestrians.

- Pedestrian Dynamics

Pedestrian Dynamics was developed by the company Incontrol Simulation Solution and association with the University of Utrecht, it can run both mesoscopic and microscopic model (Caramuta et al., 2017). This software automatically generates the routes of pedestrian and also adjusted the speed of facilities such as stairs and elevators. The output provided the results into 2D and 3D models following flow counter, density of the area and travel time map in the form of a chart or table.

- Legion

Legion was developed by the software house Legion International Limited and was implemented by the benefit-cost model. However, it could be run in the microscopic model. This software calibrated some parameters in the mathematic model by gathering the data from 14 cities (Caramuta et al., 2017). The benefit-cost model described pedestrians trying to reach the destination by minimizing a route cost. Inputs

are determined by the different characteristics of pedestrians and pedestrian behavior such as age, physical size, and walking speed. The output is presented in the origin and destination matrix (OD matrix), visualizing pedestrian speed and density.

- Simtread

Simtread was developed by Nemetschek Vectors Inc. and was implemented by the shortest path model, mostly used in evacuation planning in public spaces such as a railway station and schools (Caramuta et al., 2017). This software can input the pedestrian route, maximum speed of pedestrian and location, generated obstacles including walls or columns and the selected destination area. The results showed both the analytical and graphical projections of the measurement area, pedestrian flow rate and walking speed.

- Simwalk

Simwalk is an agent-based simulation software and consisted of the social force model, mostly used in traffic management and evacuation (Caramuta et al., 2017). This software includes various generated data, including the characteristics of pedestrians (speed, height, age, gender), clothes (uniform, swimsuit) and specific details of the pedestrian (waiting, walking). The output is shown in graphical format, following the density map, road map, speed map, and trajectories map.

- Anylogic

Anylogic was developed by the Anylogic Company and implemented both macroscopic and microscopic simulations (Caramuta et al., 2017). Inputs considered are a pedestrian activity (diameter, type of pedestrian groups) and action. The results provided some statistics (minimum, average, maximum) and data sets such as queue length and charts.

- Simped

Simped was developed by the University of Technology of Delft and consisted of the benefit-cost model, but is possible to execute in the microscopic model. The simulation considers several parameters, including the characteristics of infrastructure (length, width), pedestrians (free speed) and the public transport vehicle (number of doors and width) This software showed the interaction between pedestrians and

vehicles and distinguishes between different types of pedestrians (tourists, workers) in relation to their walking behavior. However, the layout of Simped contains only Dutch context.

Moreover, the following are softwares that were used in the analysis of evacuation scenarios with different objectives:

- Pathfinder is used to evaluate the occupant's speed and influence of exit choice in evacuation with several scenarios in the model (Kallianiotis, Papakonstantinou, Arvelaki, & Benardos, 2018).
- Pyrosim analyzes evacuation time, fluid of smoke and amount of carbon monoxide, its migration and its effects on evacuation. (Saelao, 2001)
- FDS+EVAS can generate the sources of fire and smoke, it considers the design of infrastructure guide evacuation route and safety exit design (Y. Li et al., 2017).
- BuildingExodus has been extended to model large-scale urban evacuations by including road network and open spaces around the buildings (Shi et al., 2012; Veeraswamy et al., 2018)

This thesis focused on VISWALK software due to the features supporting the analysis of pedestrian flow. For the simulation, each program uses a different output. Some programs have modules to help the customer and user simulate the data but each researcher uses a simulation program that is suitable for their research. Kim, Galiza, and Ferreira (2013) stated that after they obtained the data, they used VISSIM to simulate the pedestrian queues for finding the methods to decrease the queue and improve times spent waiting in a queue. Huang, Liu, Yu, and Wang (2013) stated that VISSIM can estimate the traffic conflicts measured at intersections and compare simulated conflicts to the real traffic data. In addition, VISSIM can help determine the optimized parameters for mix traffic conditions (Prabhu & Sarkar, 2016). PTV group produces software for pedestrians and results in similarities between Vissim and VISWALK, but VISSIM used for macroscopic models more efficiently than VISWALK. Lee and Tseng (2014) stated that they use VISWALK to forecast an evacuation time of each possible solution in order to find the result, such as to find the

minimum time spent to travel to the cinema. Some researchers generate papers to compare the simulation programs in same scenarios to find the advantages of each program. Sun, Zhang, and Chen (2013) stated that comparative analysis of two programs CORSIM and VISSIM are based on four key indices, namely software usability, average control delay, average queuing length and cross-section traffic volume.

The National Institute of Standards and Technology (NIST) is organized to promote innovation and industrial competitiveness. Martén and Henningsson (2014) used VISWALK software to verify and validate building evacuation models by the NIST standard provided.

2.3 Parameter calibration

The results of the simulation programs are contained with errors. However, without the calibration process, the models will contain higher amounts of error and will not result in realistic data. Calibration is the adjustment of model parameters to improve the reliability of models with present local behavior and traffic performance characteristics (Dowling, Skabardonis, & Alexiadis, 2004). Calibration should be performed on various components of the overall model, therefore it becomes necessary to calibrate the model before simulating the results. The objective of calibration is to improve and evaluate the model to represent the local situation in the real world.

Most pedestrian simulation software provides default values of each parameter by collecting the survey data and calibrating into a default value (Caramuta et al., 2017). The analyst classified the calibration parameters into two basic categories (Dowling et al., 2004):

- Parameters are considered and not willing to adjust.
- Parameters are less considered and willing to adjust.

For adjustable parameters divided into two cases:

- Global parameters: that is needed to calibrate first and affect the overall simulation model

- Local parameters: the specific parameters are used after calibrating global parameters and effects on the local area in the model.

The significance of parameters depends on the scope of the research study (travel time, LOS) and the effect of parameters on the model (evacuation, pedestrian flow) (Friis & Svensson, 2013). The calibration is taken into account to validate the pedestrian simulation and results in the model becoming realistic to the actual situation. This thesis will focus on calibration in VISWALK software following the previous study.

2.3.1 Two-Way ANOVA Test

ANOVA stands for Analysis of Variance is a statistical technique that explains the differences in the level of the dependent variable. ANOVA can be used in many methods, depending on the independent variable mostly used in three ways; one-way ANOVA, two-way ANOVA and n-way ANOVA.

The two-way ANOVA uses two independent variables to consider in the statistical analysis which compares the mean difference between groups. The purpose of this method is to evaluate the relationship between two independent variables on the dependent variable. VISWALK software implemented the social force model and consisted of various parameters (global and local parameters) Therefore, it virtualized the pedestrian behavior in actual situations. Gaddam, Arya, Vanumu, and Rao (2018) conducted the evacuation experiments in classrooms with different door width and age profiles and analyzed the individual interaction between pairs of parameters by using the two-way ANOVA test to minimize the error in evacuation time. The calibration parameters considered the speed and pedestrian flow behavior and multiple parameters are compared by using a two-way ANOVA test to identify the significant parameters (Prabhu & Sarkar, 2016).

2.3.2 Latin Hypercube Sampling and Cumulative Absolute Residual Value

Latin hypercube sampling (LHS) is a statistical method for generating stratified random sampling that provides an efficiency of parameters from multivariate distributions.

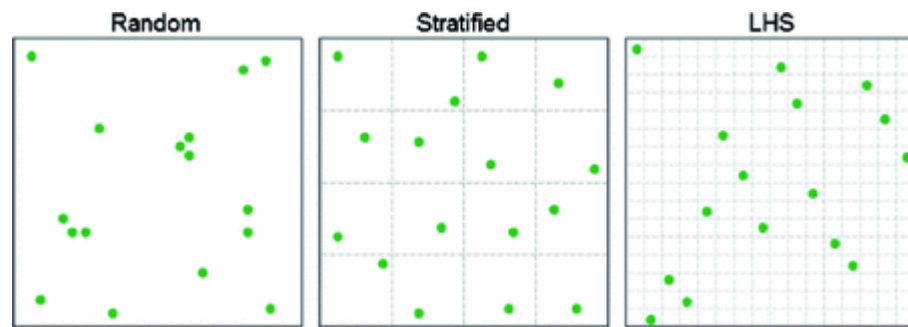


Figure 2.5 Latin hypercube sampling (LHS)

Source: (Dimitrov, Dimov, & Todorov, 2016)

Gaddam et al. (2018) used LHS for generating a set of parameters in VISWALK software (Tau, Lambda, React to N and Grid size) and evaluated the error of each parameter by cumulative absolute residual value.

2.3.3 Simple Two-Parameter Search Algorithm

In the case of two model parameters are to be optimized, and plot in contour can be used to identify the minimum error of two parameter values (Dowling et al., 2004). Firstly, analyze the acceptable ranges of the two parameters and simulate the results from varying two parameters. Finally, the results were evaluated by using the square error from each pair of parameter values and plotting the data in a contour graph to identify the lowest error of two parameters (Figure 2.6). In addition, the method considers two model calibration objectives separately by using Dual-objective, Two-parameter search algorithm (Figure 2.7)

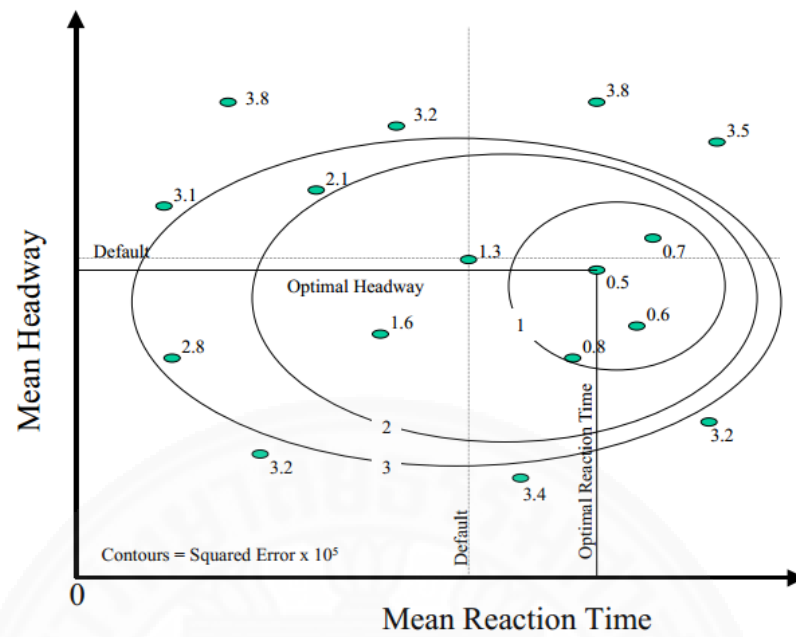


Figure 2.6 Simple two-parameter search algorithm

Source: (Dowling et al., 2004)

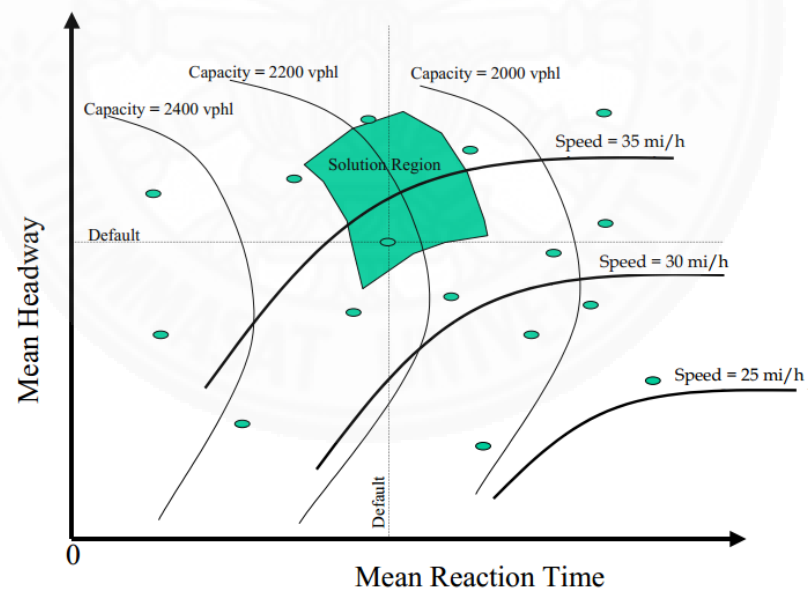


Figure 2.7 Dual-objective, Two-parameter search algorithm

Source: (Dowling et al., 2004)

2.4 Calibrated parameters on VISWALK

The previous studies researched the pedestrian simulation to represent pedestrian behaviors in the study area. The different studies used different calibration methods with different results of the parameter value. Due to walking behaviors were influenced by the feature of the location. Previous studies of calibrated parameters are reviewed below:

Prabhu and Sarkar (2016) researched pedestrian warrants for developing countries using the simulation program. The study area was selected inside Delhi Urban area in India due to the high number of pedestrians. Therefore, the filed survey was separated into two places and different peak times following 8:30 am – 9:30 am and 12:30 am – 13.:30 am. Thus, Two ways ANOVA was applied to calibrate parameters by identified and sensitivity analyses. Figure 2.8 showed the value of each parameter after calibrated.

Pedestrian Parameters	Default	Calibrated
Grid Size (m)	5.00	1.00
Queue Order	0.70	0.50
Queue Straightness	0.60	0.40
Tau	0.40	0.10
Reach to N	8.00	3.00
A Social	2.72	4.20
B Social	0.20	0.40
Side Preference	None	Left

Figure 2.8 Calibrated parameters

Source: (Prabhu & Sarkar, 2016)

The results reveal that the error percentage between the actual survey and the simulation was less than 10 %.

MRTA (2016) was conducted the simulation model to evaluate both pedestrians and vehicles. Mass Rapid Transit Authority of Thailand hired the Chaing Mai University to research the simulation model of pedestrians in the transit station. The study area was selected in MRT Sukhumvit station in Bangkok using the survey from 4:00 pm – 5:00 pm. Table 2.3 showed the calibrated value in this study.

Table 2.3 The value of each calibrated parameters

Parameters	Default value	Calibrated value
React to N	8	2
Noise	1.2	4
Lamda	0.176	0.400
VD	3	1



CHAPTER 3

METHODOLOGY

This chapter consists of the processes of research divided into 6 sub-chapters. In the first part, Study areas are divided into 2 MRT stations, namely Huai Khwang station and Sukhumvit station. Data collection described the processes of collecting data and equipment. Data analyzing evaluated the survey data and adapted the data to be input into VISWALK software. Simulation modeling displayed the overall MRT Huai Khwang station model. Parameters in VISWALK software explained the significance of each parameter in the software and the effects of parameters on the model. In the last part, The calibration procedure uses a simple two-parameter search algorithm to find the best set of parameter values.

3.1 Overall research framework

In this thesis, the study is initiated by gathering and collecting the data. There are a large number of public train stations in Thailand. Therefore, the station chosen is the MRT Huai Khwang station due to there are two levels which are easy to collect data. MRT Huai Khwang station is one of the top four stations that has a vast amount of passengers (PPD, 2012). This thesis aims to focus on pedestrian behavior in railway systems in Thailand.

Simulations are technology to simulate or test the real situations in virtual programs. This thesis uses PTV VISWALK. PTV stands for Planing Transport Verkehr and VISSIM stand for Verkehr In Städten – SIMulationsmodell (Traffic in cities - simulation model). VISSIM is a simulation program aimed towards studies of transportation within cities. It can simulate vehicles and can simulate pedestrians in which it calls VISWALK. This program is useful in simulating the pedestrians and easily creates models in which it does not overcomplicate. PTV group has a license of VISSIM to support any individual who wishes to access and use the simulation program for their thesis or research. Simulation programs are very important tools used to study the pedestrian walking behavior because it can simulate many elements of the behavior

that might not be evident to researchers instantly. The overall methods of this thesis follows the chart below.

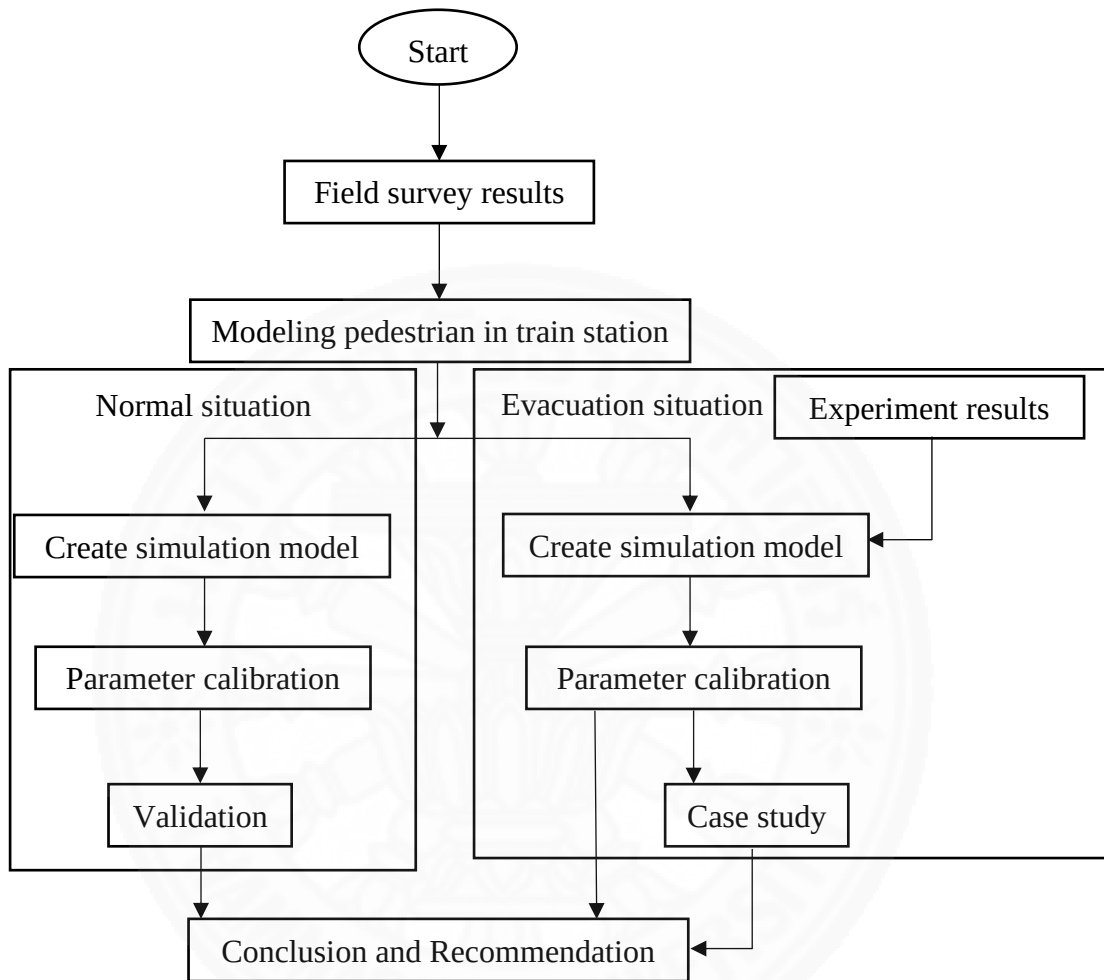


Figure 3.1 Overall research framework

3.2 Study area

This research study area was selected at the MRT Huai Khwang station, one of the most constantly congested Mass Rapid Transit stations. This station consists of 3 levels (PPD, 2012). It is an underground railway station, which is one of the Blue Lines (Chaloem Ratchamonkhon Line) located in Ratchadaphisek road. It was built underneath hotels and houses which were constructed directly above the ground.



Figure 3.2 Concourse level in MRT Huai Kwang Station



Figure 3.3 Platform level in MRT Huai Kwang Station

3.3 Data collection

The most critical aspect regarding data collection is the method to collect and its percentage accuracy. The methods to collect the data will see the usage of the video camera to record the pedestrians that pass around that area. After the video camera was used, the data were analyzed by several methods such as manual count. Different researchers use different data collection methods. Some researchers use manual counting and some researchers set up sensors.



Figure 3.4 Data collection equipment

For this research, The data was collected by two methods. The first method used manual counting to survey the MRT Huai Khwang Station. The purpose of the survey was to make the model reliable and to use real data to simulate the pedestrian in real situations. The survey was conducted on Monday, Wednesday, and Friday in the morning peak rush hour for commuters (07:30-08:30) and follows this scope:

- Count the pedestrians at the entrance (4 entrances) and check the frequency of the inbound - outbound train.
- Survey the route of pedestrians and record each pedestrians' travel time.
- Measure some data inside the MRT station such as obstacles (column or barrier), width (gate, stairs, and the escalator) and the number of steps at the stairs.

The reason for selecting these three days to initiate the survey was due to the difference between weekdays and weekends which made the data unreliable. Another purpose was to survey the problems pedestrians faced in MRT stations such as congestions and other problems inside the facilities.

The second method used video cameras to record real time, actual situations in MRT stations. The purpose was to check the time needed by pedestrians when using

the service (ticket booths, ticket machines, and passing through the gate) and find the speed of each pedestrian, with the goal to observe and visualize patterns of walking behavior and queue (order, and straightness). This method has more accuracy as it can help the model represent the real situation. Moreover, to calibrate the pedestrian behaviors with the calibration scope: pedestrian walking speed, time used by pedestrians to pass through the bottleneck, flow of pedestrian and time spent by pedestrians in queues (see in Appendix B).



Figure 3.5 Video camera capture

3.4 Data analyzing

The data were obtained from surveying, there were counted of the number of people that were circulated through the station that day. Then, a division was made into 2 groups. The first group is the group of people that entered the station from the outside. The second group is the group of people that arrived by train to the station. Also, the frequency of the train (Tao Poon bound and Hua Lamphong bound).

From the surveying process, it was found that the number of passengers will reach its peak at 7.46 - 8.00 AM. The data were analyzed by statistical methods including the speed of pedestrians, time spent to buy a ticket (counter and ticket machines) and time spent passing through the fare collection gate. Moreover, the detail of facility design was obtained by using laser measurements.

3.5 Simulation modeling

The model of MRT Huai Khwang station was generated by VISSIM software using module VISWALK to simulate pedestrian modeling. The station consisted of 3 levels:

- Base level or road level: this consists of 4 entrances directly to MRT Huai Khwang station and connects with concourse level by stairs and escalators.
- Concourse level: the main purpose at this level is to sell the tickets including ticket counters and ticket machines. In addition, pedestrians will pass through fare collection gates to platform level by 4 main stairs, 2 escalators, and 1 elevator.
- Platform level: enables pedestrians to board and arrive at the station. Departures include both of 2 bound trains (Tao Poon bound and Hua Lamphong bound)

The MRT Huai Khwang station consisted of a width of 23 meters, length of 226 meters and a depth of 19 meters. Moreover, the obstacles and facilities were measured from the field survey such as the distance between columns and width of stairs.

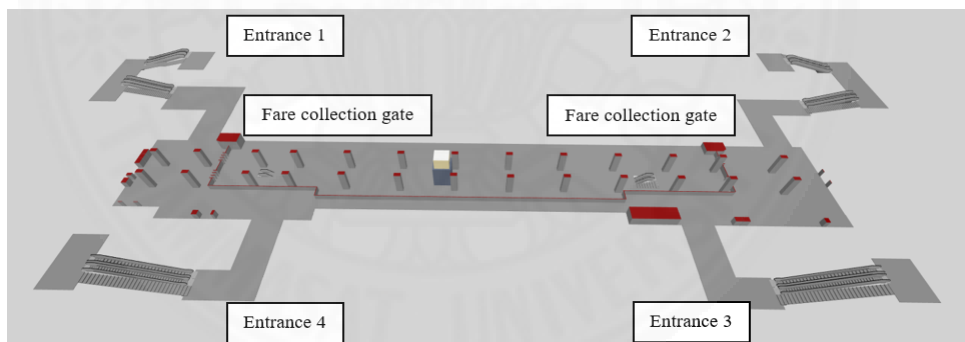


Figure 3.6 Concourse level in the simulation model

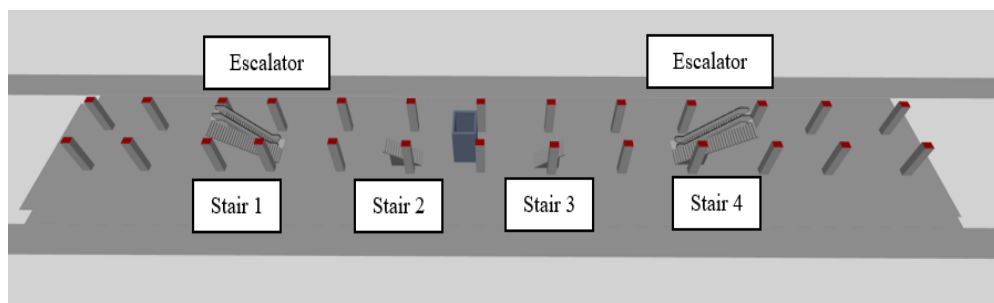


Figure 3.7 Platform level in the simulation model

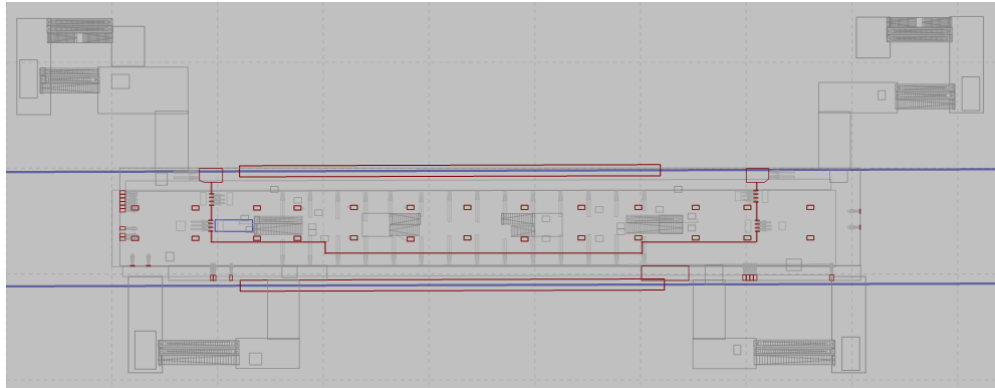


Figure 3.8 Plan view in 2D dimension

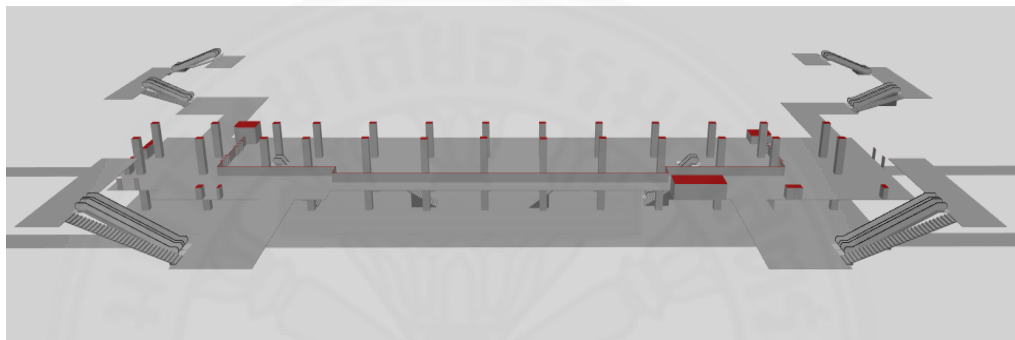


Figure 3.9 Overall MRT Huai Khwang station

3.6 Parameters in VISWALK software

The parameters affected the walking behaviors of the pedestrian in the simulation program. There are 2 types of parameters following the global parameter and the local parameter. The global parameter is a parameter that affects the overall model such as grid size and obstacle distance. The local parameter is a specific parameter that can be calibrated in varying situations and affected a part of the model such as walking behaviors. The parameters affect walking behavior in VISWALK software following (PTVGroup, 2017):

Walking Behaviors												
Select layout...												
Count: 5	No	Name	Tau	ReactToN	ASocIso	BSocIso	Lambda	ASocMean	BSocMean	VD	Noise	SidePref
1	1	Default	0.400	8	2.720	0.200	0.176	0.400	2.800	3.000	1.200	None
2	2	Elevator (In Cab)	0.256	8	2.720	0.200	0.453	0.400	2.800	3.000	0.300	None
3	3	Elevator (Alighting)	0.200	8	2.040	0.300	0.176	0.400	2.800	3.000	1.200	None
4	4	Bottomneck	0.400	4	2.720	0.200	0.850	0.400	2.800	3.000	4.000	None
5	5	Calibration	0.150	4	2.720	0.200	0.850	0.400	2.800	1.800	1.200	None

Figure 3.10 The parameter of walking behaviors

1) Tau (τ)

The parameter Tau (τ) is a value that shows the driving force in which if without, the pedestrian wouldn't arrive at their intended destination. The forces which cause them to accelerate or decelerate is included below:

$$\vec{F} = \vec{F}_{Driving} + \vec{F}_{Social} + \vec{F}_{wall} + \vec{F}_{Noise} \quad (6)$$

Tau has the dimension of time included in its calculations and ideology. Therefore, it can also be said that tau is the inertia, lag time or reaction time that is caused by pedestrians.

There are many outlining theories that may be provided with this parameter. Firstly, increasing tau decreases acceleration. Even though the pedestrians walking in the station have very similar walking speeds and very similar geometries of walking behavior, if the value of tau is different, their arrival times will definitely be different. Also, increasing tau decreases density. When a group or large number of pedestrians has to pass a bottleneck, all of those pedestrians except for the very first few will have to slow down due to the social forces. Lastly, if the tau is increased, the radius is increased. When the tau is increased, when the pedestrian walks around the corner the radius at which they turn around the corner will be increased.

2) Lambda (λ)

Lambda (λ) is the notion in which the events or persons at the back (the back of the pedestrian's head, or the one that they had just passed) do less impact on them than the one that is ahead of them or the one that they had not passed yet. The thing that is being affected is pedestrian movement. It is both a psychological and social force, and values that have to be taken into account of in this parameter is the angle between the current direction of a pedestrian and the source of a force, and a factor, denoted w, that is calculated for all social forces that stop the suppressing force.

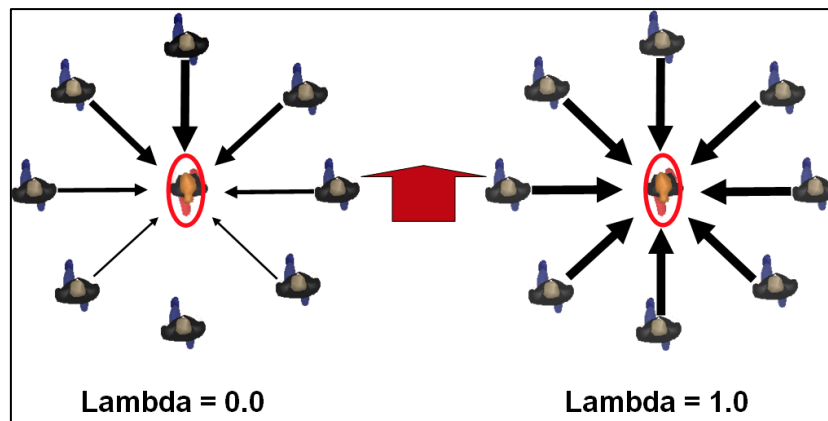


Figure 3.11 The difference between values of Lambda

Source: (PTVGroup, 2017)

Figure 3.8 expresses the parameter Lambda in more expressive detail. For a lambda of 1.0, reactions or forces from every direction and angle relative to the pedestrian would trigger a change in them. Also, the force applied from behind the pedestrian would be less prevalent in the value of 0.0. In a Lambda of 1.0, the pedestrian would be more reactive to their surroundings, resulting in more efficient traveling time and more efficient movement through congested areas such as bottlenecks.

3) A soc isotropic & B soc isotropic

A soc isotropic, along with B soc isotropic and Lambda govern one of the two forces between pedestrians. The parameter d showcases the distance between pedestrians (body to body surface) while the variable n is the unit vector, which points from one to the other.

The range of usage of these values can be wide. For example, the larger the value of A social isotropic, the smaller the flow through the bottleneck. In a single file movement, the flow is larger if A social isotropic is smaller.

4) A soc mean & B soc mean

In the case of these variables, A soc mean describes the strength while B soc mean describes the typical range of the social force that exists between any two pedestrians.

5) VD

When two pedestrians pass each other while both are walking in opposite directions, they may try to avoid colliding with each other. Then, the pedestrians will swerve their movement to avoid collision, which is the distance that will be left between each other. The value of VD may change with the distance that is left between the pedestrians trying to avoid colliding with each other.

6) Noise

The greater the value of this parameter, the greater the random force. This random force is added to the simulation. The random forces account for all the disturbances that might slow the pedestrians down or otherwise lose their momentum. The systematically calculated forces in the program will account for if the pedestrian remains below their desired speed for a period of time.

7) React to N

The parameter React to N determines the number of pedestrians that are considered for the social force. For example, if the value of N is decreased, the pedestrians' jitter and density are increased. This makes it easier for the groups of pedestrians to pass through bottlenecks. Also, increasing N leads to stronger avoidance of groups. In other words, pedestrians in large numbers tend to make other people want to avoid them.

8) Side preference

This variable determines whether opposing pedestrians that are moving into each other's range would prefer to stay to the left or the right of each other when passing each other. -1 is for the preference of the right side, 1 is for the preference of the left side. The value of 0 is for no preference.

9) Queue order and Queue straightness

These two variables provide the shapes and patterns of pedestrian queue. Their value range is from 0.0 to 1.0. The higher or closer to 1.0 these parameter values get, the more straight the queue will appear in the overhead.

10) Grid size

The value of grid size determines the size of the cells of a grid that shows the efficiency in the setting of maximum distance on the range in social force. Figure 3.12 defines the set of the distance between the pedestrian on the eight neighboring cells. The default value is 5. If the grid size is decreased, the maximum distance of influence is decreased.

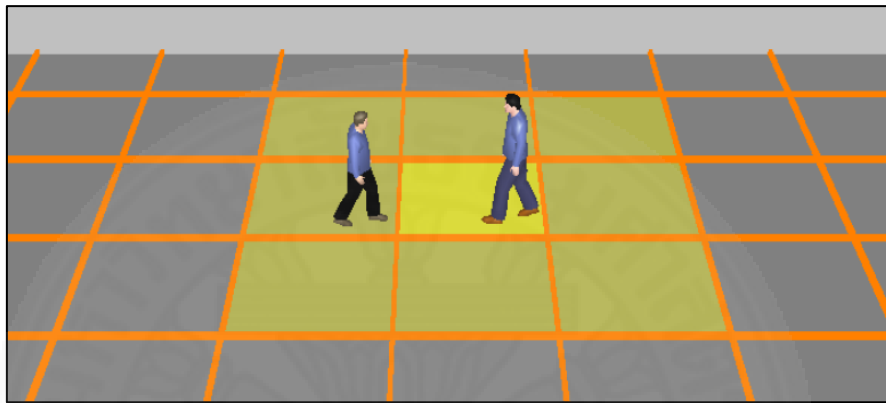


Figure 3.12 Grid in VISSIM software

Source: (PTVGroup, 2017)

11) Obstacle distance

The effect of obstacle distance is made in order that the pedestrians keep distances from obstacles including walls or columns. The default value is 0.5 meters. If this parameter is increased, the distance of pedestrians from obstacles will gradually increase.

In addition, some parameters made the model more reliable in relation to the data input in VISWALK software including:

- Pedestrian input: generate the number of pedestrians.
- Pedestrian route: set origin-destination of pedestrian and the proportion of each route.
- Pedestrian type: generate the characteristic of pedestrians (male, female, elder)
- Pedestrian composition: input the proportion of pedestrian type and set the speed of each pedestrian type

The advantages of VISWALK software are simulated real situations with a large number of functions, including the detail of results (queueing time, area result and travel time), 3D simulation and allowing varying input file format.

3.7 Parameter calibration procedure

Calibration is the method used to find and minimize the error of parameters and find the appropriate value for each situation (normal or evacuation). The parameters in VISWALK software consist of various functions to present the pedestrian behaviors in different situations according to a real-world situation. In this research divided the calibration methods into 2 parts, the first method evaluated the relationship between 2 parameters and the second method used grid analysis to find the optimal value of both parameters.

In order to determine the walking behavior parameters, the subject of survey data must be determined, such as following pedestrians' speed, pedestrians walk in the same and opposite direction, pedestrians pass through the bottleneck and pedestrians queue patten. The next step finds the pair of influence factors according to the subject of calibration by sensitivity analysis. With a small change in the respective parameter values, the individual results will behave (Gaddam et al., 2018). In this approach, simulations are evaluated by varying selected two parameters values and maintaining consistency of other parameters.

For calibration of the parameters, the grid analysis was used to minimize the error of each situation in the pedestrian simulation model. To evaluate the error in this study, the Sum square error (SSE) function must be deployed. This is accomplished by adjusting the pair of parameters and while maintaining the other parameters and having them remain constant.

$$\text{Sum square error} = \sum_j^m \sum_i^n (P_j - O_{ij})^2 \quad (7)$$

Where: P_i = Field survey result of calibration criteria at observation point j

O_i = Simulation result of calibration criteria (see Table 4.9) at simulation i
observation point j

m = Number of observation points

n = Number of simulations

This study used the grid analysis to find the optimal value of two parameters and separated the searching step into two phases. The first phase was to simulate the boundary value of the grid graph by varying each of the two parameters and setting boundaries when increasing and decreasing the value of parameters, resulting in finding the error in the model (congestion). Thus, the maximum and minimum of boundaries were set in a grid graph. Next, the simulation was taken into account to find the error of selected parameters by gradually increasing the parameter value with 1-2 intervals and used comparison of the results of simulation and survey data by Sum square error (SSE). The results were plotted in grid graph it showed the optimal value of two parameters.

After obtaining the initial value of the selected parameters, the second phase is evaluated using the parameters with a small interval. The objective of the second phase is to minimize the error of parameters using SSE as similar to the first phase. This phase set the new boundary around the minimum errors in the grid graph and adjusted the parameter with 0.5 intervals. The average SSE of each pair of parameters was calculated to find the new optimal value and also plotted the SSE value in grid graph.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Field survey results

The survey was conducted in MRT Huai Khwang station in the morning at 7:30 – 8:30 AM. using 3 days on 22th (Monday), 24th (Wednesday) and 26th (Friday) May 2019. The survey data were obtained from two types of methods: first using manual count by 6 surveyors and second method using 5 video cameras to record the pedestrian behavior, pedestrian routes, pedestrian speed and time spent using services in MRT Huai Khwang station. In addition, the survey included the headway of the train, the waiting time of passengers and the dimension of obstacles.

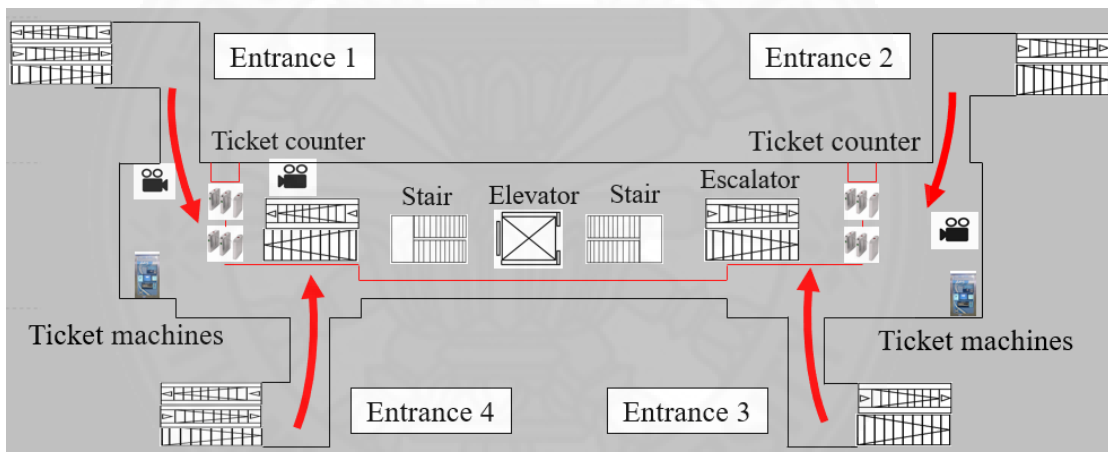
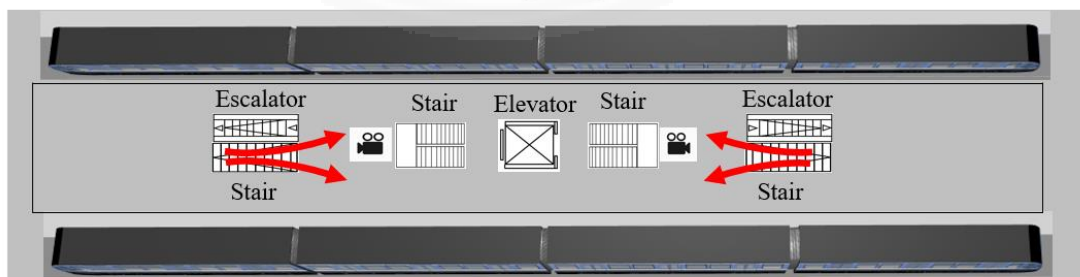


Figure 4.1 The position of surveyors and video cameras on the concourse level

Hua Lamphong bound



Tao Poon bound

Figure 4.2 The position of surveyors and video cameras on the platform level

Figures 4.1 and 4.2 show the position of surveyors and video recording at different levels in MRT stations. The objective of manual count is to record the pedestrians that traveled inside and exited at the entrance of MRT station. The details of the survey data are shown in the following sections.

4.1.1 Facility and obstacle dimension

MRT Huai Khwang station consists of many facilities including stairs, escalators, elevators and fare collection gates. The National Fire Protection Association (NFPA) is an international standard which specifies fire protection and life safety requirements for fixed guideway transit and passenger rail systems during the emergency situations. Thus, the standard NFPA-130 sets the minimum width design standard for each facility.

Table 4.1 Facility dimensions in MRT Huai Khwang Station

Facilities	Actual width (m)	NFPA-130 Minimum width required (m)
Stairs	2.00	1.12
Escalators	1.15	1.12
Exit corridors	6.00	1.73
Fare collection gate	0.58	0.51
Elevator	0.96	-

Source: (NFPA, 2014)

The results came from the measurement using a laser tape sensor. Comparing the width between the actual design and the NFPA-130 standard shows the facilities inside MRT Huai Khwang station passing all minimum requirements in NFPA-130.

In addition, there are many obstacles in MRT Huai Khwang station such as columns, ticket counters, and ticket machines.

Table 4.2 Obstacle dimensions in MRT Huai Khwang Station

Obstacles	Dimension (m)
Columns	0.81 x 1.33
Ticket counters	4.00 x 4.41
Ticket machines	0.51 x 0.82
ATM machines	0.53 x 1.01

The size of obstacle affected the pedestrian movement and pedestrian behavior according to the previous study (Q. Li, Gao, Chen, & Kang, 2019). The survey measured the distance between obstacles and exit corridors. The purpose of measuring the distance is to validate the model in VISWALK software and made the model realistic.

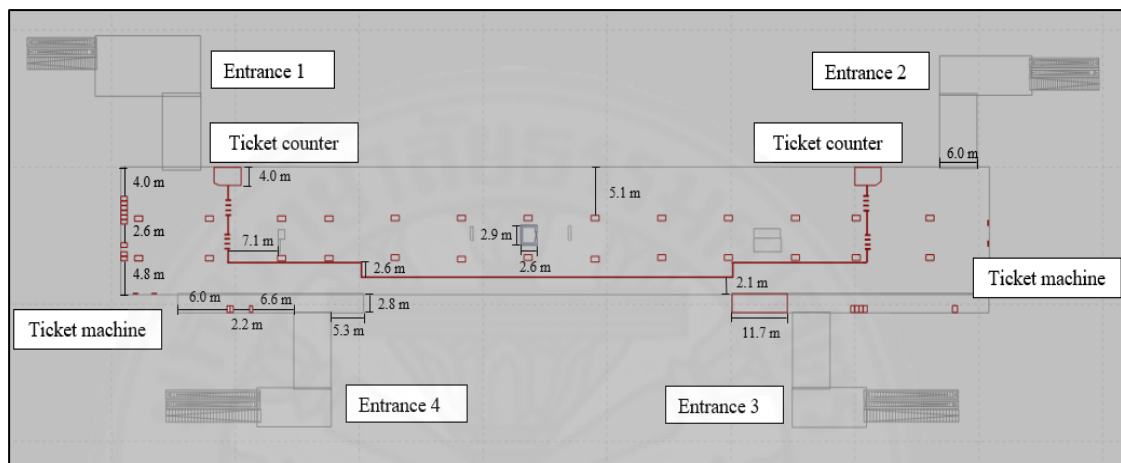


Figure 4.3 The obstacle distance on concourse level

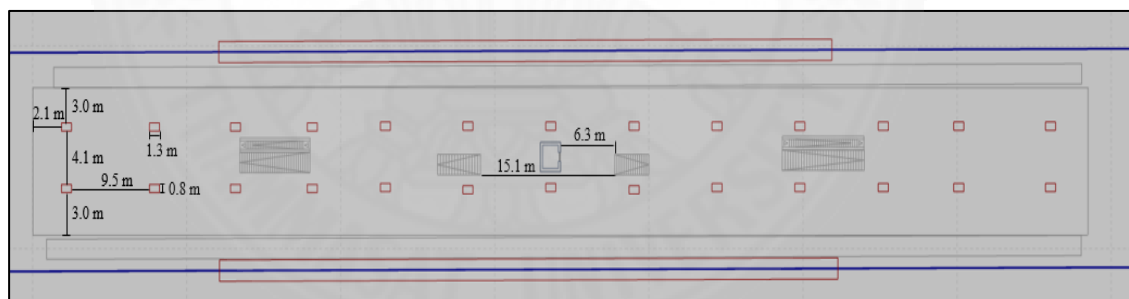


Figure 4.4 The obstacle distance on platform level

The result from the survey data showed the total number of facilities in MRT Huai Khwang which includes 14 escalators, 10 stairways, 3 elevators, 12 fare collection gates and 2 swing gates (this gate is normally used for staff, a disabled person or a person with large luggage, and opens manually). The total number of obstacles are; 26 columns, 2 ticket counters, 4 ticket machines and 17 automatic machines (ATM or top-up mobile). The overall design in MRT Huai Khwang Station adhered to the safety design standards of both Thailand and internationally.

4.1.2 The volume of passengers

The survey was conducted in the morning rush hours. A large percentage of the people in Bangkok which work within the Central Business District commute to the workstation by using the underground train. The data was collected at 4 entrances/exits on the concourse level and platform level by two methods, including manual counts and recording video cameras. The results came from the average 3 days survey and divided into 15-minute intervals in order to increase the accuracy and started from 7.30 to 8.30.

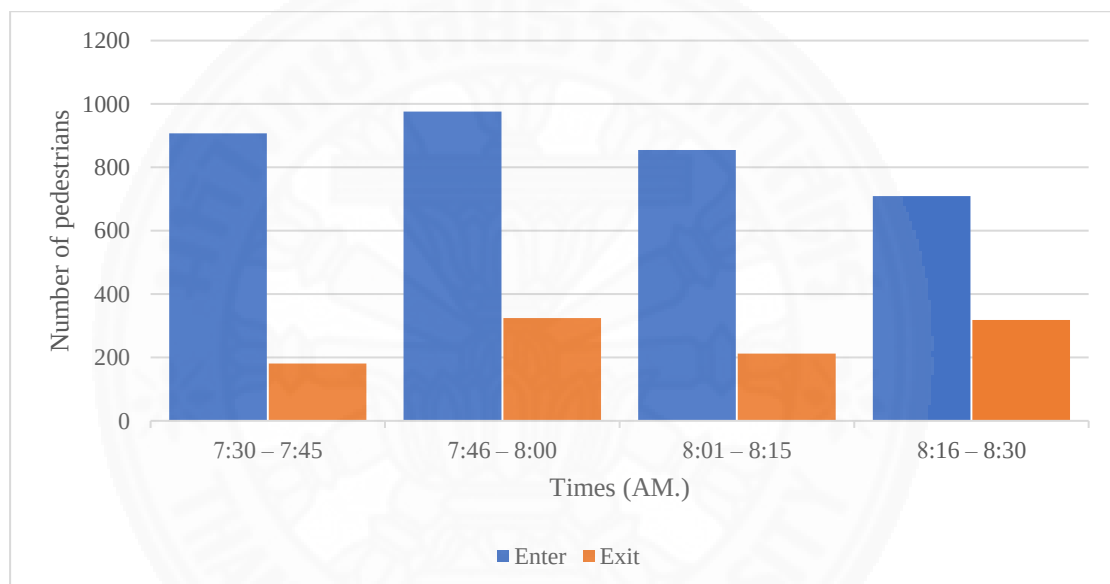


Figure 4.5 Number of passengers in-out station

The results reveal that the peak time for pedestrians using the underground train is at 7:46 – 8:00 AM. (976 people). Passengers enter the station more often than they exit at this time. This is due to the station being close to large residential areas and a bus stop.

4.1.3 Details of the train

MRT Huai Khwang station consists of 2 directions for commuters, Tao Poon bound and Hua Lamphong bound. The surveyors recorded the headways of the train, time passengers spent waiting in a queue and the number of passengers on each train. According to MRTA information of service, it was revealed that MRT operates 18

hours per day on both weekdays and weekends from 6:00 to 24:00. The frequency of the train arriving at each station separates into rush hours (6:00-9:00, 16:30-19:30) and normal hours. The fluctuation in train station schedules can directly affect pedestrian behavior.

Table 4.3 The detail of both train directions

Bound	Time	Average		
		Headway of train (s)	Passenger queue time (s)	Number of passengers (passengers/train)
Tao Poon	7:30 – 7:45	215	32	104
	7:46 – 8:00	182	35	148
	8:01 – 8:15	176	36	88
	8:16 – 8:30	220	33	110
Hua Lamphong	7:30 – 7:45	167	23	36
	7:46 – 8:00	193	25	72
	8:01 – 8:15	171	25	46
	8:16 – 8:30	203	24	72

Due to MRTA operations within rush hours (6:00-9:00), the frequency of the train will increase to handle the massive amount of passengers.

From the results, it showed that the average headway of Hua Lamphong bound train (183 s) was less than the Tao Poon bound train (198 s) because the direction of Hua Lamphong bound train travels towards the Central Business District. It resulted in more passengers boarding the train in this direction. However, the number of passengers in Tao Poon bound train (113 passengers/train) was higher than the Hua Lamphong bound train (57 passengers/train) due to passengers from the suburbs entering the city center. In addition, Hua Lamphong bound train (24 s) uses less waiting time than Tao Poon bound train (34 s) due to the density of passengers on each arriving train.

4.1.4 Pedestrian free flow speed

The free flow speed of pedestrians was collected in MRT Huai Khwang station by using the video camera at the concourse level since space available affects the speed of pedestrians. Unfortunately, the limitation of space in the platform level made pedestrian speed unreliable and different from the actual scenario so, the data were

collected only at the concourse level. In case of calculation, the speed of each pedestrian was calculated by the formula shown below:

$$V = \frac{S}{T} \quad (8)$$

Where: V = Speed (m/s)
 S = Distance (m)
 T = Time (s)

The space in this study was measured at the concourse level with no obstacles. The speed collected from the survey was called free-flow speed and the time was recorded from the video recording.

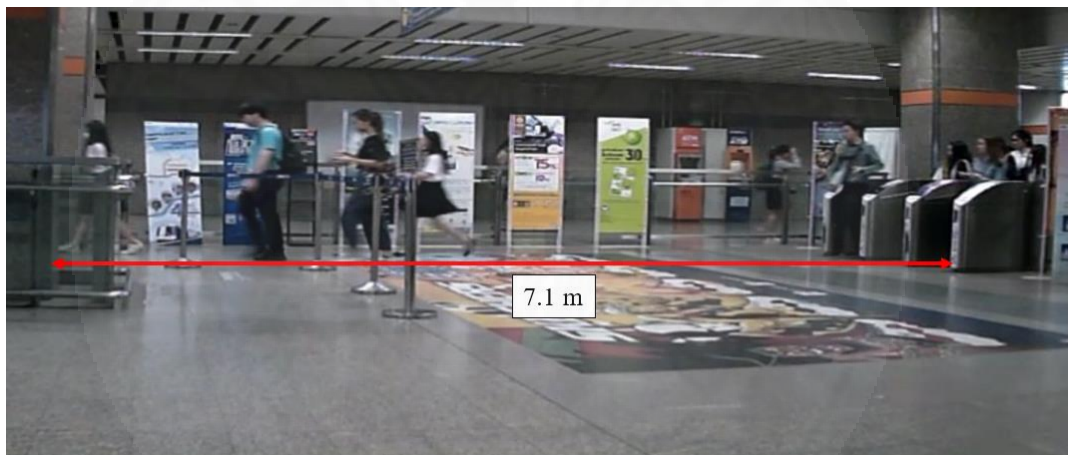


Figure 4.6 Measuring the distance between the fare collection gate and column

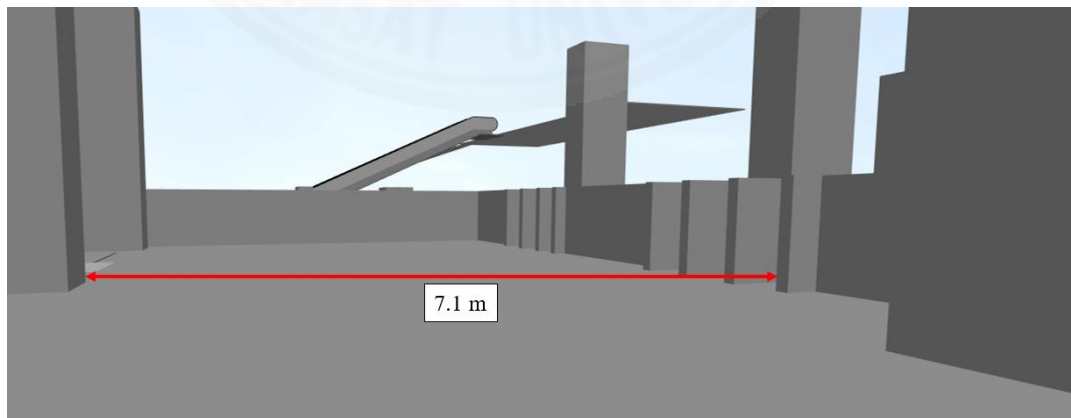


Figure 4.7 Collection area in VISWALK software

The result divided time into a 15 minutes interval, identical to the previous subject of the survey.

Table 4.4 The pedestrian walking speed in MRT Huai Khwang Station

Time	Walking speed of pedestrian (km/hr)			
	Maximum	Minimum	Average	SD
7:30 - 7:45	6.22	3.45	4.91	0.49
7:46 - 8:00	6.04	3.23	4.85	0.65
8:01 - 8:15	6.20	3.40	4.35	0.58
8:16 - 8:30	6.20	3.73	4.73	0.55
Total	6.22	3.23	4.71	0.59

Table 4.4 showed that the results were collected from 200 people in MRT Huai Khwang station. The walking speed of each pedestrian is different depending on the working time in each company and the rush of the individual.

4.1.5 Pedestrian routes

The routes of pedestrians were collected by using manual counts (6 surveyors) on the concourse level and the platform level. The pedestrian route reflects their decisions and intentions once they arrived at the station. The data were collected on a number of pedestrians' routes from the arrival point to the destination point. There are three choices that pedestrians are forced to decide when they arrive. This includes ticket counters, ticket machines and walking through fare gates.

Table 4.5 The pedestrian routes on the concourse level

	Entrance/Exit	Destination (%)		
		Pass through gates	Ticket counters	Ticket machines
Origin	Entrance 1	94.76	3.67	1.57
	Entrance 2	92.38	6.48	1.14
	Entrance 3	93.53	4.23	2.25
	Entrance 4	91.58	6.32	2.10

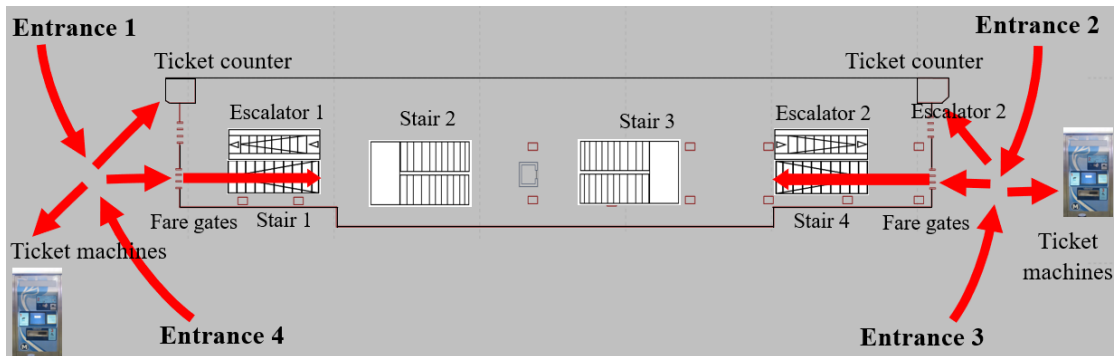


Figure 4.8 Pedestrian routes on the concourse level

Table 4.5, the results showed that most pedestrians prefer to use the MRT member card to pass through the fare gates. This is due to the reduced time spent waiting in queue to buy tickets at the ticket counters, more so during rush hour.

On the other hand, after the pedestrians pass through fare collection gates, all pedestrians are meant to descend to the platform level to wait in queue for the arriving train. There are two routes at the platform level; Hua Lamphong bound and Tao Poon bound.

Table 4.6 The pedestrian routes on the platform level

Origin	Destination (%)		
	Stairs	Hua Lamphong bound	Tao Poon bound
	Stair 1	67.66	32.34
	Stair 4	60.57	39.43

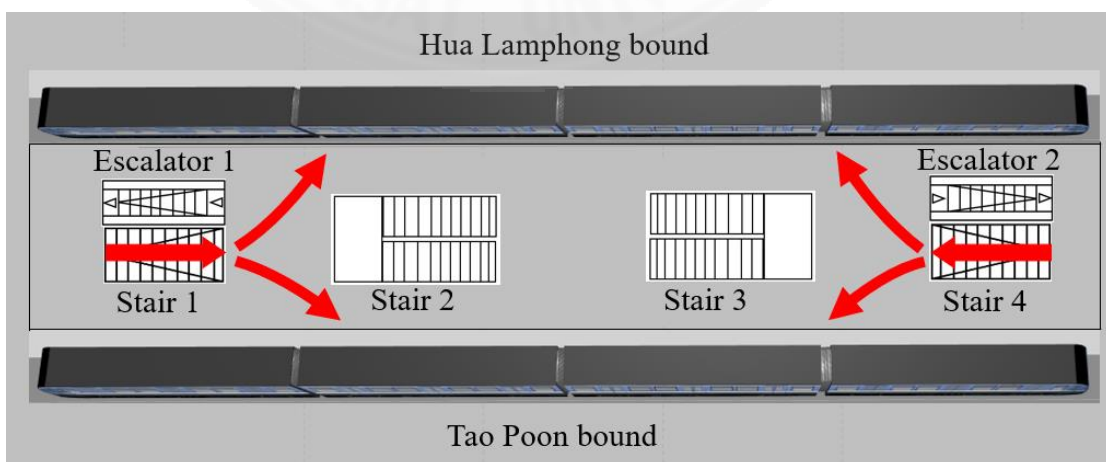


Figure 4.9 Pedestrian routes on the platform level

The results showed that Hua Lamphong bound is the more congested route due to work commitments of pedestrians in the morning. This results in longer queue lengths.

In addition, the surveyors cover the number of passengers in the departure train (Hua Lamphong bound and Tao Poon bound). After all passengers depart, there are two routes for the passenger to arrive at the concourse level, including stair 1 and stair 4.

Table 4.7 The pedestrian routes from the trains

Origin	Destination (%)		
	Train	Stair 1	Stair 4
Origin	Hua Lamphong bound	32.70	67.30
	Tao Poon bound	36.20	63.80

Table 4.7 showed that passengers prefer to use stair 4 due to the location of entrance 2 and entrance 3 being located close to business headquarters.

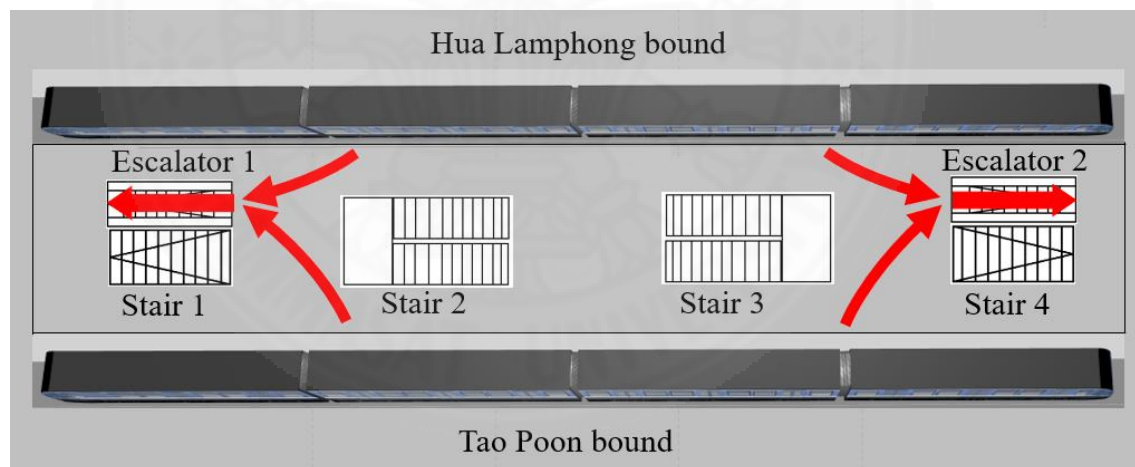


Figure 4.10 Pedestrian routes from the trains at the platform level

After pedestrians used escalators to the concourse level, they are meant to pass through the fare collection gates. There are four routes from the escalators that connect between the concourse level and platform level including entrance 1 and entrance 4, and entrance 2 and entrance 3.

Table 4.8 The pedestrian routes from the stairs

	Escalator number	Destination (%)			
		Entrance 1	Entrance 2	Entrance 3	Entrance 4
Origin	Escalator 1	87.80	-	-	13.20
	Escalator 4	-	62.60	37.40	-

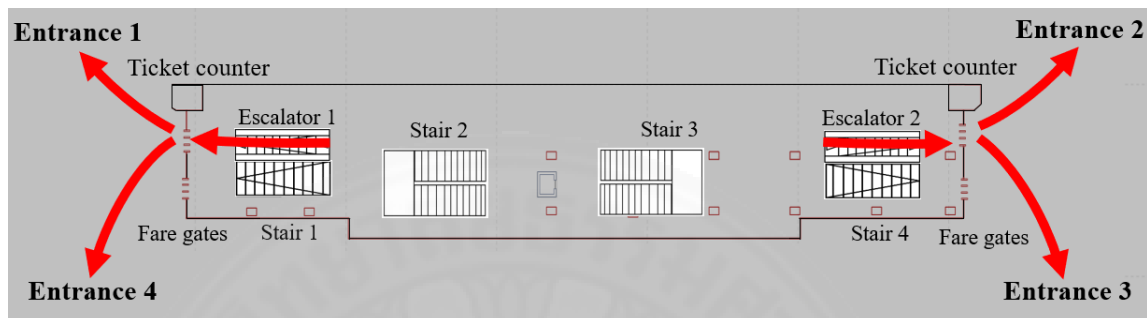
**Figure 4.11** Pedestrian routes from the stairs to all entrances

Table 4.8 showed that pedestrians preferred to go the entrance 1 and entrance 2 from the escalator 1 and escalator 2.

4.1.6 Time spent using service in the station

In MRT Huai Khwang station, there are three main points for spending additional time by passengers on the concourse level. These are ticket counters, ticket machines, and the fare collection gates.

4.1.6.1 Time spent on buying a ticket at the ticket counter

Some passengers rarely use the underground train to travel in Bangkok. They do not prefer to pay the money for an MRT member card. In MRT Huai Khwang Station, the passengers have two choices to either buy a ticket at the ticket counter or at the ticket machines. Most pedestrians preferred to buy a ticket at the ticket counter due to the fact that the concept of service staff assisting them is more attractive than a ticket machine. The data was collected by 200 passengers at MRT Huai Khwang Station.

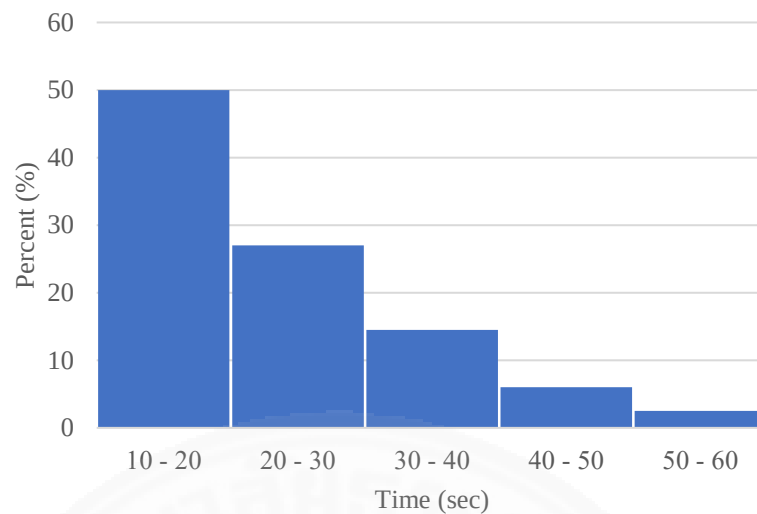


Figure 4.12 Time spent at the ticket counter

The results found that the average time spent at the ticket counter is 20 seconds with the following statistics; the maximum time is 59 seconds, the minimum time is 10 seconds and the standard deviation is 10.68. The ticket counters are located between entrance 1 and entrance 4, and entrance 2 and entrance 3.

4.1.6.2 Time spent on buying a ticket at the ticket machine

There are 4 ticket machines at the concourse level to service the passengers without staff members and this decreases the queue length at the ticket counters. The data was collected by 100 passengers in MRT Huai Khwang station.

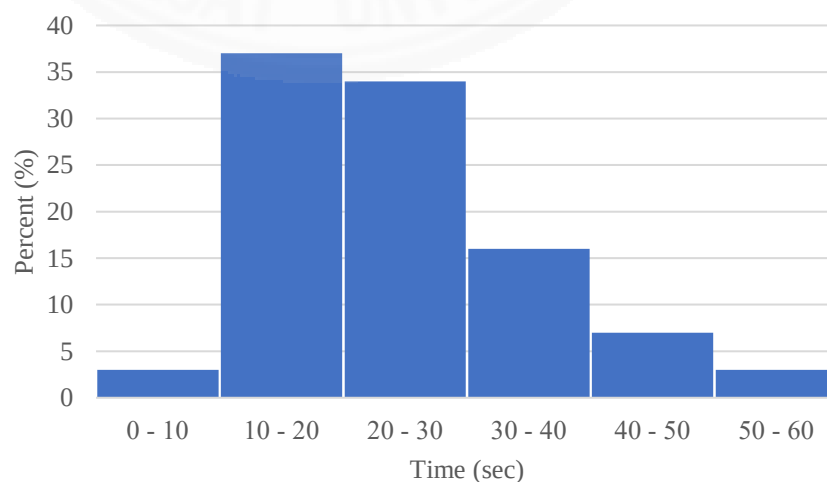


Figure 4.13 Time spent at the ticket machine

The results reveal that the average time spent at the ticket machine is 23 seconds with the following statistics; the maximum time is 60 seconds, the minimum time is 8 seconds and the standard deviation is 10.59. Some passengers, especially the elder, do not prefer to use the ticket machine because of the complicated process of using an automated machine to purchase a train ticket.

4.1.6.3 Time spent on passing through the fare collection gates

Most passengers who travel through the stations have the MRT member card due to the fact that more than 90 % of the existing railway passengers always use the railway system in Bangkok. After passengers have a ticket, they should pass through the fare collection gates to board the train as rapidly as possible on the platform level. All pedestrians in the station have to pass this point. This results in the model being more reliable. The data was collected by 200 passengers in MRT Huai Khwang Station by video recording.

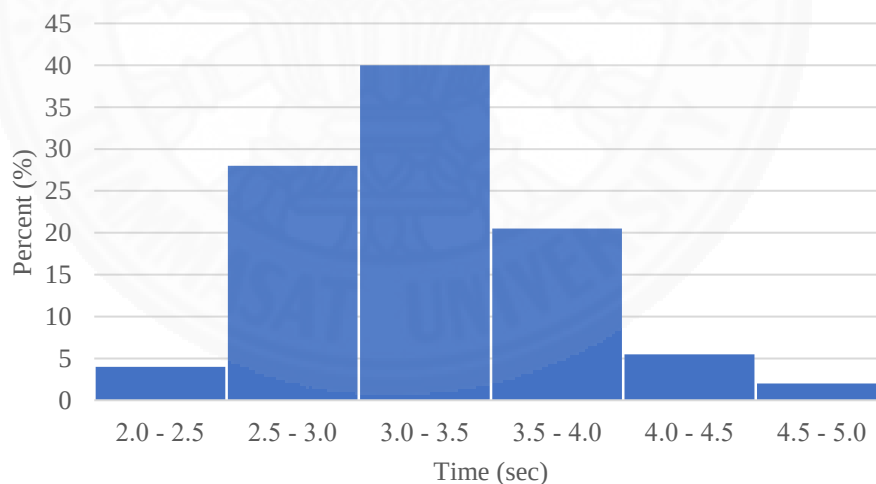


Figure 4.14 Time spent on passing through the fare gates

The results found that the average time passing through fare gates is 3 seconds with the following statistics; the maximum time is 4.75 seconds, the minimum time is 2 seconds and the standard deviation is 0.48. In addition, there are the swing gates serviced for staff members, the disable or people with large luggage sizes.

4.1.7 Queue patterns

When large amounts of passengers enter the station, it resulted in longer waiting times in queues. However, there are many points in this station that queues occurred both at the concourse level and the platform level. Queueing area on the concourse level consists of ticket counters, ticket machines, and fare collection gates that occur during peak hours in the morning.



Figure 4.15 Queue patterns on the concourse level

Moreover, queue length in the platform level is longer than the concourse level due to passengers waiting for the train and congestions inside the train. The congestion occurs during rush hours and event periods of the weekday.



Figure 4.16 Queue pattern on the platform level

The results of the survey showed that queue pattern in MRT Huai Khwang station more linear in shape. Passengers wait in a queue. However, unethical behavior such as queue cutting does occasionally take place.

4.2 Parameter calibration

Calibration is a process to validate the data under various methods that are significant and acceptable for worldwide study. There are widely used methods to calibrate parameters and models. The parameter is a measurable factor that is useful or critical when identifying a system.

This study used grid analysis to calibrate the parameters in VISSIM/VISWALK software to present the pedestrian behaviors in the train stations in Bangkok. Grid analysis was used to find the optimal value of both parameters in the pedestrian simulation model. The parameters in the simulation models include Tau (τ), Lambda (λ), Grid size, VD, Noise, React to N, Queue order and Queue straightness are calibrated to represent the actual situation at this train station. In order to calibrate the parameters, it was separated into two steps. First, Determine the parameters that effecting to each specific calibration criteria by:

- Review of literatures and software manual.
- The experiment set up by simulation to observe the effect of each parameter to the criteria selected

Table 4.9 Calibration criteria

Subject of calibration	Parameters
Pedestrian walking speed	Tau (τ) and Lambda (λ)
Flow of pedestrian	Grid size and VD
Time used by pedestrians to pass through the bottleneck	Noise and React to N
Time spent by pedestrians in queues	Queue order and Queue straightness

Table 4.9 showed the influence of each pair of parameters according to the VISSIM manual and the results from adjusting the parameter. Consequently, the grid analysis is taken into account to calibrate both parameters of each subject. The results of each observation points are showed in Appendix B.

4.2.1 Calibration using pedestrian walking speed

The walking speed of pedestrians was adjusted by two parameters using grid analysis. Tau (τ) and Lambda (λ) affected the walking speed of pedestrians in the model due to the two parameters being measured by minimizing the walking speed between results from the survey and simulation program. The error between the pair of parameters was applied by sum square error method (SSE), after that it was plotted in the grid. There are two phases of calibration in the grid analysis method. In the first phase, the boundary of two parameters was set from the limitation of each parameter. Thus, Tau (τ) was set from 0.1 to 0.4 with the interval of 0.1 and Lambda (λ) was set from 0.2 to 1 with the interval of 0.2. The results from the first phase showed that the value of Tau (τ) was 0.1, while Lambda (λ) was 0.8 under the SSE approximately 0.64 in Figure 4.16

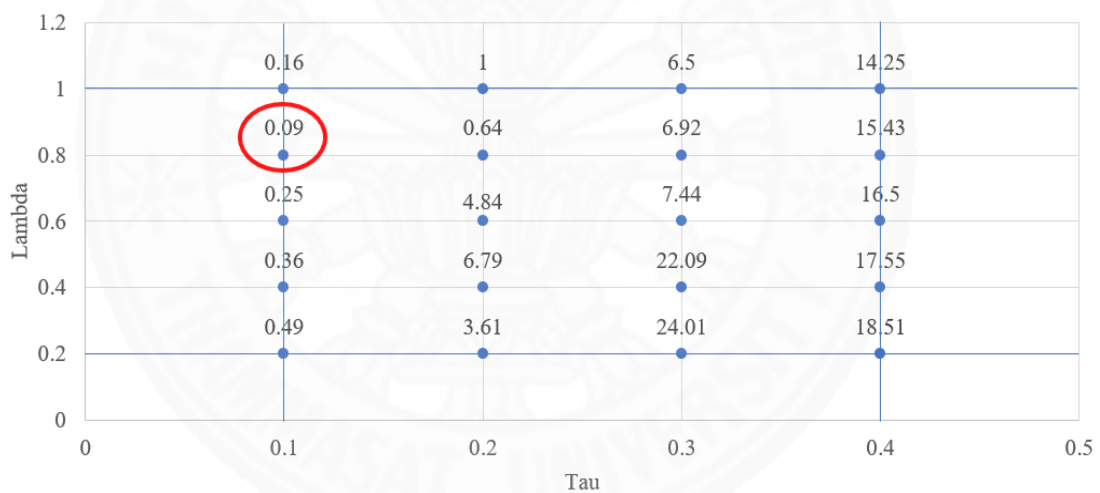


Figure 4.17 Grid analysis of the SSE of pedestrian walking speed (initial phase)

After the initial results were identified, the next phase revised the results of the two parameters. In the second phase, the boundary of Tau (τ) and Lambda (λ) was set in the area of the initial results due to re-checking for the optimal value of the two parameters. Thus, Tau (τ) was refined from 0.1 to 0.15 with the interval of 0.05 and Lambda (λ) was refined from 0.8 to 0.95 with the interval of 0.05. The results of the second phase found that Tau (τ) was 0.15 and Lambda (λ) was 0.85. In addition, the SSE of the second phase was reduced from 0.64 to 0.01 in Figure 4.17.

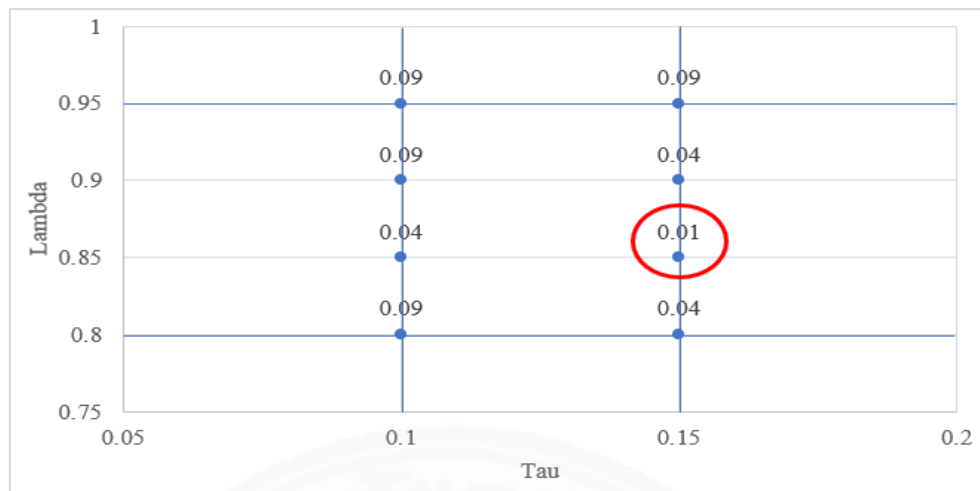


Figure 4.18 Grid analysis of the SSE of pedestrian walking speed (second phase)

Tau (τ) is decreased from the default value because the walking speed of pedestrians in train stations is faster than the normal situation. Due to the data were collected from the rush hour in the morning. Lambda (λ) is increased from the default value because force from a pedestrian on the back is equal to the force of pedestrian on the front.

4.2.2 Calibration using time used by pedestrians to pass through the bottleneck

MRT Huai Khawng station consisted of the congestion zone causing a bottleneck such as stairs or escalators, while there are React to N and Noise affecting the interaction between pedestrians that were specific at the bottleneck in VISWALK software. The two parameters were considered by minimizing time used by pedestrians to pass through at the stairs. Thus, the boundary of React to N was set from 2 to 10 with an interval of 2 and Noise was set from 1 to 5 with an interval of 1. The initial results of pedestrians passing through the bottleneck showed that the optimal value of React to N was 2 and Noise was 3 under the SSE of 1.69 in Figure 4.19.

After obtaining the initial results, the second phase was identifying a new boundary with it and narrowing down to the value in the first phase. React to N was refined from 1 to 3 with the interval of 1 and Noise was refined from 2 to 4 with the interval of 0.5. However, the results from the second phase found that the optimal value

of two parameters was duplicated as the initial results. Thus, React to N was 2 and Noise was 3 under the SSE of 1.69 in Figure 4.20.

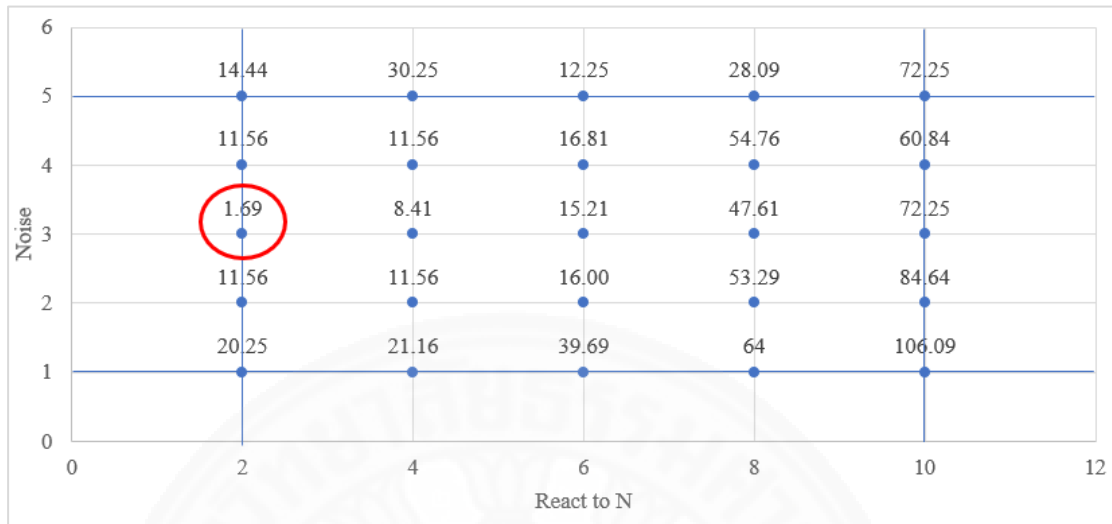


Figure 4.19 Grid analysis of the SSE of time used by pedestrians to pass through the bottleneck (initial phase)

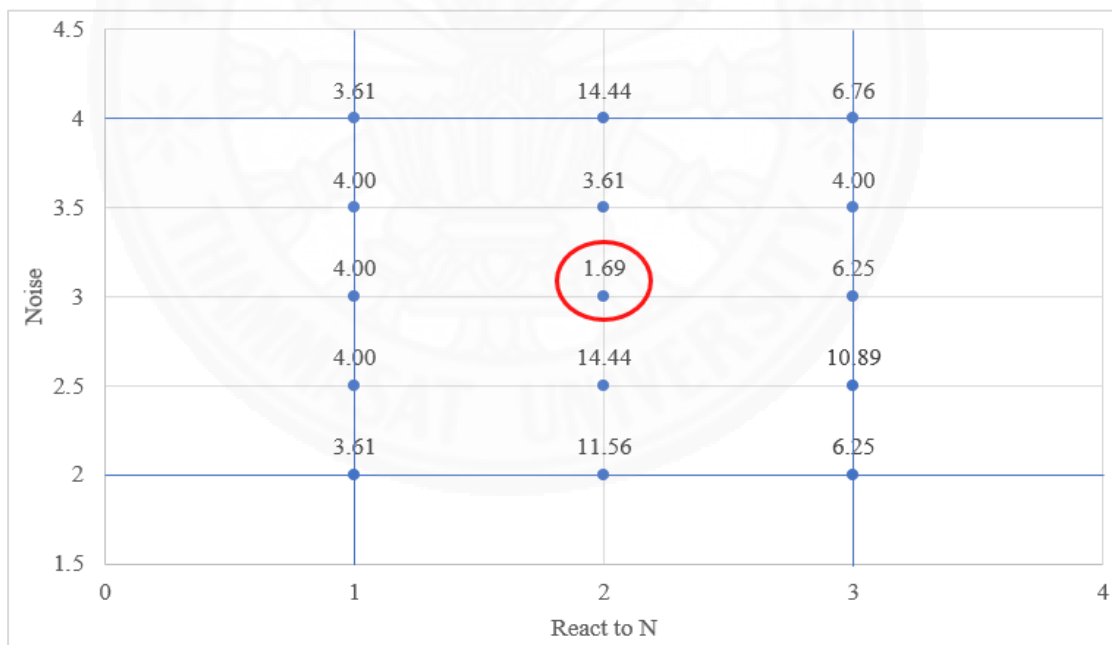


Figure 4.20 Grid analysis of the SSE of time used by pedestrians to pass through the bottleneck (second phase)

React to N is decreased from the default value due to most pedestrians consider pedestrian from the front (left and right). On the other hand, Noise is increased from

the default to prevent a deadlock at the bottleneck by comparing with time used by pedestrians to pass through the bottleneck

4.2.3 Calibration using flow of pedestrians

There are many points in MRT Huai Khwang station which pedestrians could pass through the opposite direction such as the passageways and boarding/exiting the train. Thus, VISSIM/VISWALK software consisted of the Grid size and VD that affected the pedestrian behaviors when passing each other. The pair of parameters were considered different from other parameters by comparing the flow of pedestrians pass through the opposite direction snapshots between the survey and simulation program with the volume of pedestrians Figure 4.21.



Figure 4.21 Grid analysis of the SSE of flow of pedestrian



(a) Screenshot from a video camera

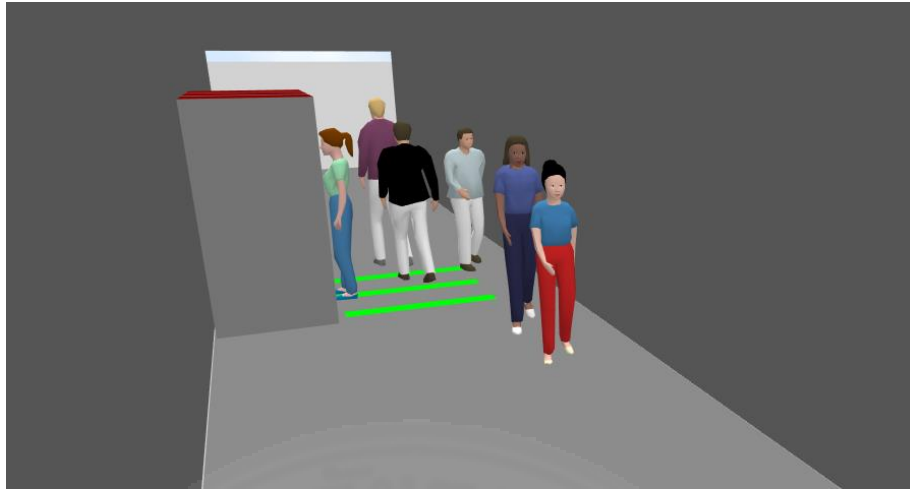


(b) Screenshot from the simulation program

Figure 4.22 Comparison between (a) and (b) at 7:31-7:45



(c) Screenshot from a video camera



(d) Screenshot from the simulation program

Figure 4.23 Comparison between (c) and (d) at 7:46-8:00



(e) Screenshot from a video camera



(f) Screenshot from the simulation program

Figure 4.24 Comparison between (e) and (f) at 8:01-8:15



(g) Screenshot from a video camera



(h) Screenshot from the simulation program

Figure 4.25 Comparison between (g) and (h) at 8:16-8:30

Grid size is decreased from the default value because the space available among pedestrians is required less than the default value. VD is decreased from the default value since the avoidance of pedestrians pass through the same and opposite directions is less than the default value.

4.2.4 Calibration using time spent by pedestrians in queues

The queue of pedestrians was taken into account to consider the pedestrian behavior at the train station due to the most service in MRT Huai Khwang station should be performed in queues in order to use the service. At the concourse level, there are

three points that caused the queue of pedestrians to build up including ticket counters, ticket machines, and fare collection gates. On the other hand, queue length was found on the platform level due to the demand of passengers traveling in Bangkok. The two parameters were Queue order and Queue straightness which affected the queue behaviors in VISWALK. Pairs of parameters were measured (SSE) by minimizing the error between the time spent by pedestrians in queues from field survey and simulation model. In the first phase, Queue order was set from 0.7 to 1.0 with an interval of 0.1 and Queue straightness was set from 0.2 to 1 with an interval of 0.2. The results from the first phase showed that the value of Queue order was 1.0, while Queue straightness was 1.0 under the SSE approximately 4.41 in Figure 4.26.

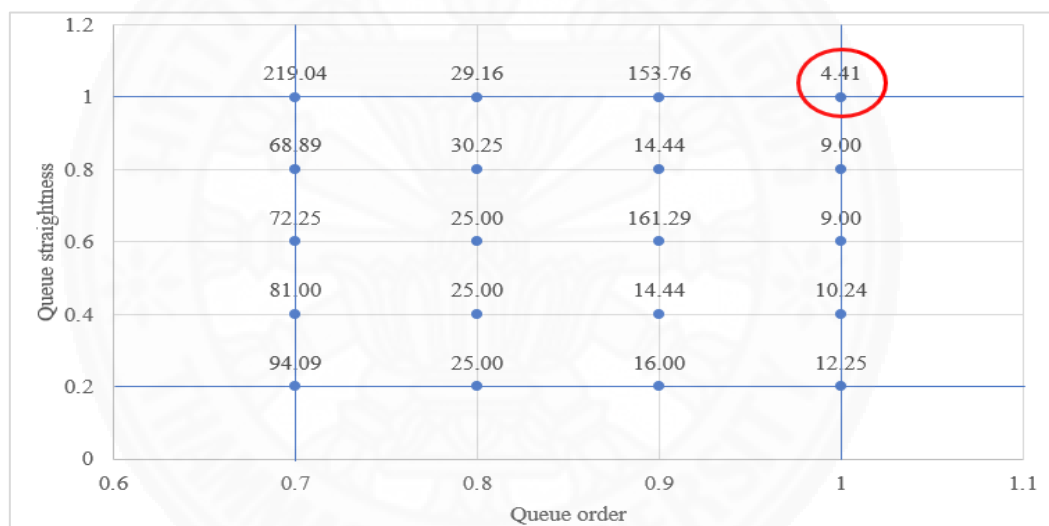


Figure 4.26 Grid analysis of the SSE of time spent by pedestrians in queues (initial phase)

Once the initial value of the two parameters was obtained, the second phase is conducted, where the boundaries of each pair of parameters were conducted while narrowing down the interval. Thus, Queue order was refined from 0.95 to 1.00 with an interval of 0.05 and Queue straightness was refined from 0.80 to 1.00 with an interval of 0.05. The results of the second phase found that Queue order was 1.00 and Queue straightness was 1.00. However, the results from the second phase found that the optimal value of the two parameters was duplicated as the initial results. Thus, Queue order was 1.00 and Queue straightness was 1.00 under the SSE of 4.41 in Figure 4.27.

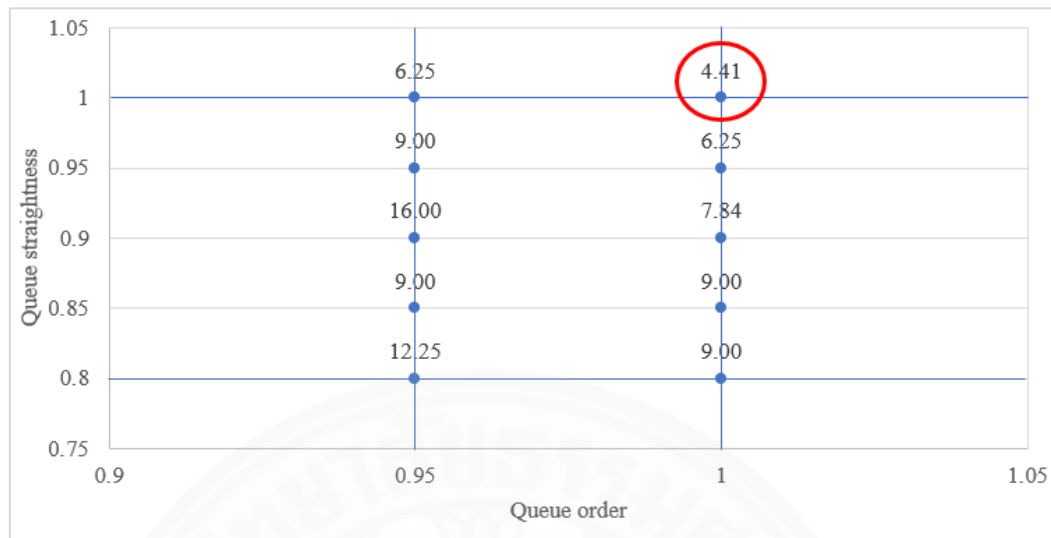


Figure 4.27 Grid analysis of the SSE of the time spent by pedestrians in queues (second phase)

Queue order and Queue straightness are increased from the default value due to the pedestrian line up in a straight queue more than the default value.

4.2.5 Summary calibrated parameters values

The overall walking behavior is taken into account to examine the accuracy of the model in VISWALK software including Tau (τ), Lambda (λ), React to N, Noise Grid size, VD, Queue order, and Queue straightness. All parameters are considered in the simulation model to validate the significance of the model by checking the number of pedestrians at the destination point. The number of pedestrians is affected by the delay in the simulation model that occurred by the congestion at the model (Figure 4.27) due to the insignificant of parameters. Therefore, If there is a delay in the results, the number of pedestrians at the destination would be checked. Moreover, there are errors during simulation such as the error in software due to adjusting the parameters (Figure 4.28).

Table 4.10 Summary of calibrated parameters values

Parameters	Values
Tau	0.15
React to N	2.00
AsocIso	2.72
BsocIso	0.20
Lambda	0.85
AsocMean	0.40
BsocMean	2.80
VD	2.00
Noise	6.00
SidePref	None
Grid size	2.75
Queue Order	1.00
Queue Straightness	1.00

Table 4.10 showed each value of walking parameters after satisfying the grid analysis method. The result reveals that this parameter set could apply to the simulation model with the minimum delay.

**Figure 4.28** The congestion and errors during simulation

4.3 Parameters validation

The validation of the parameter set was considered in this study due to confirmation that the parameter set could put in other models of the railway station in Bangkok. Thus, the behavior of pedestrians in Thailand are calibrated according to the survey data of walking behavior in MRT Huai Khwang station.

MRT Sukhumvit station was selected to validate the parameters set. Due to the fact that the annual report showed the MRT Sukhumvit station containing the highest number of passengers (PPD, 2012) because of its location in the city centre. MRT Sukhumvit Station is one of the blue lines in Bangkok that is located adjacent to Asok Montri road and connects to BTS Asok station. The details of Sukumvit station are that it contains four levels. They are the base level, underpass level (Metro mall), concourse level (ticket seller), and platform level (board the train in two directions). This station is suitable to check the parameter set due to the variance of scenarios such as the congestion period and flow period which involves examining all of the walking behavior. The survey data was collected at MRT Sukhumvit station in the morning from 7.30 to 8.30 with three days of weekdays (11th, 12th, 13th of June, 2019) similar to the survey from MRT Huai Khwang station. In addition, there are two methods such as manual counting, and video recording that were used to survey the MRT Sukhumvit station. The data were analyzed by averaging three days and classifying into a subject for comparing the parameters.

The examination of parameters set is discussed in this section. In addition, this section includes a comparison of the parameter sets between this study and the previous study in Thailand and other countries.



Figure 4.29 The platform level in MRT Sukhumvit station

4.3.1 Comparison and discussion of parameter sets

The comparison is taken into account to find the minimum error of each parameter sets since the past unit to the present. In order to validate the parameter set, the subject of calibration is used to set the criteria with the percent error. The parameter sets were separated into the four sets including the default value, this study, Chaing Mai (MRTA, 2016), and foreign countries (Prabhu & Sarkar, 2016). The criteria for checking the errors include pedestrian speed, pedestrians pass through the bottleneck, pedestrians passing in opposite directions, and queue patterns. Thus, the value of a pair of parameters is different due to the different methods used to calibrate the parameters of each study.

4.3.1.1 Pedestrian walking speed

The parameters are Tau (τ) and Lambda (λ) that affect the walking speed of pedestrians in VISSIM software. There are four parameter sets that compare to each other.

Table 4.11 Each value of Tau (τ) and Lambda (λ)

Default value		MRTA (2016)		Prabhu and Sarkar (2016)		Calibrated parameters (this study)	
Tau	Lambda	Tau	Lambda	Tau	Lambda	Tau	Lambda
0.400	0.176	0.400	0.400	0.100	0.176	0.150	0.850

Table 4.11 showed the value of parameters (Tau and Lambda), Tau was not calibrated in MRTA (2016) parameters. On the other hand, Lambda was not calibrated in Prabhu and Sarkar (2016). Therefore, the default value is replaced on parameters which were not calibrated.

The walking speed was collected from the survey in the MRT Sukhumvit station in the morning from 7:30 am to 8:30 am similar to the survey from MRT Huai Khwang station with the same methods.

Table 4.12 The comparison of walking speeds

	Actual survey	Default value	MRTA (2016)	Prabhu and Sarkar (2016)	Calibrated parameters (this study)
Times	Speed (km/hr)	Error (%)	Error (%)	Error (%)	Error (%)
7.31 - 7.45	1.67	19.8	18.6	25.7	3.6
7.46 - 8.00	4.58	32.1	16.8	9.4	1.5
8.01 - 8.15	4.49	38.8	25.4	8.5	1.8
8.16 - 8.30	4.58	6.8	10.3	13.8	0.2

Table 4.12 showed the walking speeds and the errors of each parameter set. The results revealed that the average minimum error found on the parameter set of this study is 1.78 percent error, followed by Prabhu and Sarkar (2016) of 14.34 percent error, MRTA (2016) of 17.76 percent error, and the default value with 24.34 percent error.

From theoretical point of view (social force model) in case of the pedestrian in train station, Tau (τ) should be decreased from the default value due to the walking speed of pedestrians increasing because of the pedestrian hurry to get on the train and out of the station. The pedestrian walking speed in the train station is higher than the pedestrian walking in open spaces. The default value appropriates for pedestrians walking in open spaces. On the other hand, Prabhu and Sarkar (2016) are suitable for pedestrian crossing on the road. MRTA (2016) did not calibrate the Tau (τ) so the default value will be replaced.

The calibrated value of Lambda (λ) was less than the default value possibly because the distance of pedestrian from the back is relatively equal to the distance of pedestrians on the front. When Lambda equal to 1, it means that the distance of pedestrian from the back equal to the distance of pedestrian on the front. Most pedestrians keep distance from the pedestrian on the front for avoiding the accident. The default value is suitable for pedestrian walking in a large space. While MRTA (2016) provided that the pedestrian will keep the distance of pedestrian from the back more than pedestrian the front due to the limited space in train station. Prabhu and Sarkar (2016) did not calibrate the Lambda (λ) so the default value will be replaced

4.3.1.2 Time used by pedestrians to pass through the bottleneck

Noise and React to N are the parameters that affect the pedestrians passing through the bottleneck in MRT Sukhumvit station. The bottleneck occurred at the stairs, escalators, and narrow passageways due to the high volume of pedestrians during peak rush hours. There are six case scenarios that were used to compare the time of pedestrians passing through a bottleneck with different values of parameter sets.

Table 4.13 Each value of Noise and React to N

Default value		MRTA (2016)		Prabhu and Sarkar (2016)		Calibrated parameters (this study)	
Noise	React to N	Noise	React to N	Noise	React to N	Noise	React to N
1.200	8.000	4.000	2.000	1.200	3.000	3.000	2.000

Table 4.13 showed the different value of Noise and React to N with different studies, Noise was not calibrated in Prabhu and Sarkar (2016). Thus, the default value is replaced on parameters that were not calibrated.

The six case scenarios came from a video camera recorded at the stairs with different time periods in the MRT Sukhumvit Station.

Table 4.14 The comparison of time used by pedestrians to pass through the bottleneck

	Actual survey	Default value	MRTA (2016)	Prabhu and Sarkar (2016)	Calibrated parameters (this study)
Cases	Time (sec)	Error (%)	Error (%)	Error (%)	Error (%)
Bottleneck 1	21	66.67	19.05	28.57	9.52
Bottleneck 2	34	61.76	17.65	41.18	5.88
Bottleneck 3	23	73.91	30.43	21.74	13.04
Bottleneck 4	31	67.74	22.58	38.71	12.90
Bottleneck 5	43	44.19	11.63	48.84	2.33
Bottleneck 6	24	66.67	25.00	29.17	12.50

Table 4.14 showed the value of time and the error of parameter sets with the different studies. The results reveal that the average minimum error found on the parameter set of this study is with a 9.40 percent error, followed by MRTA (2016) at 21.06 percent

error, Prabhu and Sarkar (2016) at 34.70 percent error, and the default value with 63.49 percent error.

From theoretical point of view (social force model) in case of the pedestrian in train station, React to N should be decreased from the default value because most pedestrians consider pedestrians at the front (left and right). When the pedestrians walk through the limited space, the concentration of pedestrians is focused on the pedestrians on the front. The default value is suitable for the pedestrian in the congested area and Prabhu and Sarkar (2016) appropriate for pedestrian walking in the groups. MRTA (2016) proper for pedestrian walking in the passageway at the train station.

The calibrated value of Noise was greater than the default value to prevent the bottleneck. Due to there are many congestions of pedestrians at the stairs and escalators in MRT Sukhumvit station. Thus, the default value appropriate for the deadlock occurred in some areas. MRTA (2016) survey at the train station that consists of many points of bottleneck but it no deadlock occurred in all bottlenecks. Prabhu and Sarkar (2016) did not calibrate the Noise so the default value will be replaced

4.3.1.3 Flow of pedestrians

The parameters were Grid size and VD that affect the pedestrians passing in the opposite direction. Therefore, the pedestrians would pass each other in narrow spaces such as the passageway in MRT Sukhumvit station.

Table 4.15 The value of Grid size and VD

Default value		MRTA (2016)		Prabhu and Sarkar (2016)		Calibrated parameters (this study)	
Grid size	VD	Grid size	VD	Grid size	VD	Grid size	VD
5.000	3.000	5.000	1.000	1.000	3.000	2.750	2.000

Table 4.16 showed the pair value of Grid size and VD with the different parameter sets. The grid size was not calibrated in MRTA (2016) and VD was not calibrated in Prabhu and Sarkar (2016). Thus, the default value is replaced on parameters that were not calibrated.

The data were classified into four periods of time between 7.30 to 8.30 and the survey data showed the volume of pedestrians at the surveying area.

Table 4.16 The comparison of the flow of pedestrians

	Actual survey	Default value	MRTA (2016)	Prabhu and Sarkar (2016)	Calibrated parameters (this study)
Times	Flow of pedestrian (ped/15min/m)	Error (%)	Error (%)	Error (%)	Error (%)
7.30 - 7.45	90	14.4	10.0	5.6	2.2
7.46 - 8.00	66	19.7	9.1	16.7	3.0
8.01 - 8.15	71	14.1	11.3	11.3	0.0
8.16 - 8.30	66	22.7	9.1	9.1	3.0

Table 4.16 showed the number of pedestrians and the error of each parameter sets with different periods of time. The result reveals that the average minimum error found on the parameter set of this study is with a 2.07 percent error, followed by MRTA (2016) at 9.86 percent error, Prabhu and Sarkar (2016) at 10.65 percent error, and the default value with 17.74 percent error.

The calibrated value of Grid size was less than the default value possibly because the space of pedestrians in the train station is limited. Besides, the space of pedestrian is decreased due to the congestion in train station. The default value is suitable for the pedestrian in the open space without congestion. Prabhu and Sarkar (2016) appropriate for pedestrian in the congested area with limited space available. MRTA (2016) did not calibrate the Grid size so the default value will be replaced.

The calibrated value of VD was less than the default value due to the space of pedestrian walking is limited. When pedestrians pass through the same and opposite directions, they required some space between each other for avoiding the accident. The default value appropriates for separated lanes (walking opposite directions). MRTA (2016) is suitable for pedestrians walk through the narrow space with the opposite directions. Prabhu and Sarkar (2016) did not calibrate the VD so the default value will be replaced.

4.3.1.4 Time spent by pedestrians in queues

Queue order and Queue straightness are the parameters that affect the queue behavior in VISWALK software. In MRT Sukhumvit station, the queue occurred both at the concourse level and the platform level in terms of using the service at the station such as ticket counters, ticket machines, entering the fare collection gates and waiting in queues for the train.

Table 4.17 The value of Queue order and Queue straightness

Default value		MRTA (2016)		Prabhu and Sarkar (2016)		Calibrated parameters (this study)	
Queue Order	Queue Straightness	Queue Order	Queue Straightness	Queue Order	Queue Straightness	Queue Order	Queue Straightness
0.700	0.600	0.700	0.600	0.500	0.400	1.000	1.000

Table 4.19 showed the value of Queue order and Queue straightness with the different studies of parameter sets. Queue order and Queue straightness were not calibrated in MRTA (2016). Thus, the default value is replaced on parameters that were not calibrated.

The four cases of queue pattern came from the video camera recorded at the fare collection gates on the platform level.

Table 4.18 The comparison of time spent by pedestrians in queues

	Actual survey	Default value	MRTA (2016)	Prabhu and Sarkar (2016)	Calibrated parameters (this study)
Cases	Time (sec)	Error (%)	Error (%)	Error (%)	Error (%)
Queue 1	181	22.65	20.44	43.65	0.55
Queue 2	76	32.89	28.95	84.21	3.95
Queue 3	157	16.56	11.46	33.76	1.91
Queue 4	113	34.51	34.51	67.26	2.65



(a) Screenshot from a video camera



(b) Screenshot from simulation program (this study parameter set)

Figure 4.28 Comparison queue behaviors between (a) and (b)

Table 4.18 showed the time of queue passing fare collection gates and the error of each parameter sets with different cases. The results reveal the average minimum error found on the parameter set of this study is with a 2.27 percent error, followed by (MRTA, 2016) with a 23.84 percent error, the default value of 26.66 percent error, and (Prabhu & Sarkar, 2016) with 57.22 percent error.

The calibrated value of Queue order and Queue straightness were greater than the default value possibly because the video recording showed all pedestrians in the queue line up in a straight queue. In addition, if the value of Queue order and Queue straightness is decreased, the shape of a queue will tangle up and time spent by pedestrians in queues will increase. In train stations, the queue of the pedestrian will

perform line up in straight queue. The default value is suitable for queue of pedestrians with undisciplined and no straightness. on the other hand, Prabhu and Sarkar (2016) appropriated for pedestrian waiting for crossing roads without line up in straight.

4.4 Application

There are many applications of pedestrian simulation that depend on the different scopes of the research such as the evacuation or operating the new transit stations. This study considers pedestrian evacuation due to there has been no emergency situation in train station in Thailand. Evacuation is the process of emergency response to manage a crowd of people to move out of building safely during the emergency circumstances. Local and international evacuation standards should comply with both facility dimensions and evacuation time. The objective of this study is to simulate the evacuation of a pedestrian in MRT Huai Khwang station in Bangkok, Thailand. VISSIM/VISWALK software is applied to simulate the pedestrians' evacuation time where the simulation inputs are collected from the site including the facilities dimension, the number of pedestrians and pedestrian speed. On the other hand, the evacuation time in both scenarios (base case scenario and worst case scenario) satisfies both the requirements at the peak 15-min volume in 2019 and 2027. In addition, there should be additional emergency exits at the fare collection gate to overcome the ridership growth.

Most of the researchers study the parameters that affect pedestrian evacuation with architectural design and evacuation behaviors. Previous studies analyzed and classified the parameters that affect the pedestrian behaviors. Y. Li et al. (2017) studied the behavior of pedestrians in the high temperature during fire which blocks the exit path. Smoke from fire affects the limit of visibility, causing difficulty to evacuate pedestrians from the building (Chen et al., 2019; P. Wang & Cao, 2019). Evacuation time is longer than a normal situation because the density is high due to congestion under emergency situation (Shi et al., 2012). Normally the speed of pedestrians varies due to a person's characteristics example age, sex, apparent, etc and environment condition such as visibility and bottleneck (Kallianiotis et al., 2018).

In Thailand, there are also limited number of previous studies about fire safety. The design of exit door width effects on the evacuation, the results showed that large

of exit door size evacuation time will be less and smock curtain not effect on evacuation (Sukkiwanut, 2011). From the study of fire protection system in a hospital using the National Fire Protect Association (NFPA) and Ministry of Interior regulations, it was found that there are some problems in fire protection system occurred due to lack of system monitoring (Saelao, 2001).

4.4.1 Evacuation time

This model provides evacuation time to 3 points (Figure 4.29 and Figure 4.30); 1) evacuation time from the platform to the next floor (t_1), 2) evacuation time to fare collection gates (t_2), and 3) evacuation to station's exit (t_3). According to NFPA standard and Ministry of Interior regulations, the evacuation time should not be exceeded the minimum required time

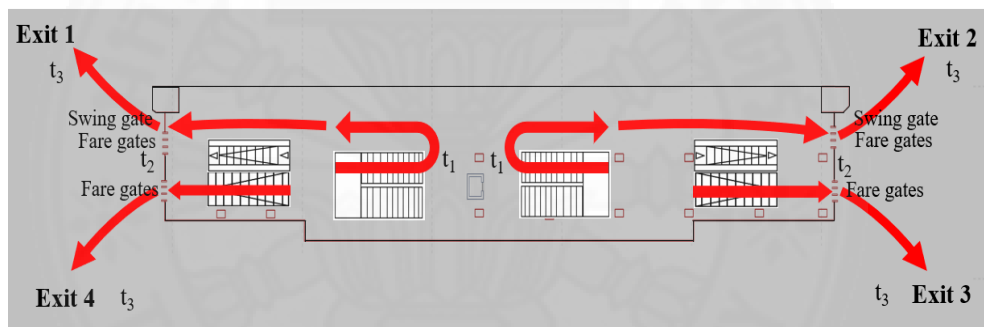


Figure 4.29 Evacuation routes on the concourse level

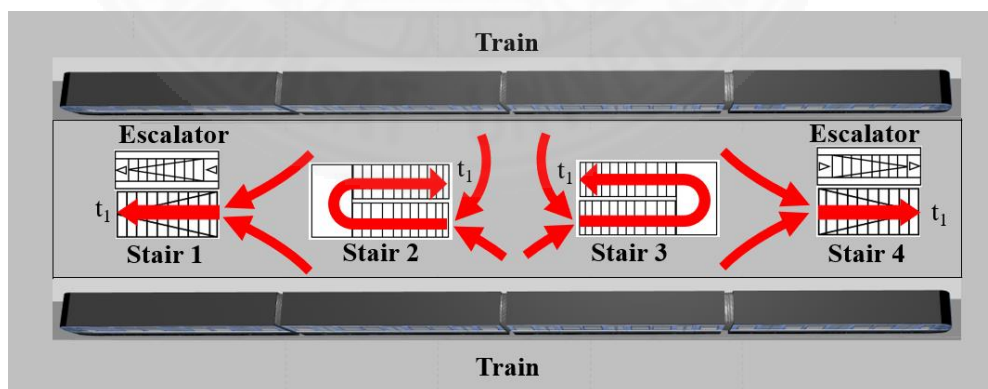


Figure 4.30 Evacuation routes on the platform level

4.4.1.1 National Fire Protection Association (NFPA) standards

NFPA-130 is an international standard which specifies fire protection and life safety requirements for fixed guideway transit and passenger rail systems. In this study

the standard of evacuation time. NFPA-130 set the maximum time of evacuation from the transit station using 2 criteria:

- Evacuation from the platform to the next adjacent floor should be 4 minutes or less and the farthest distance on the platform towards safety not more than 91.4 meters.
- Evacuation from the platform to station's exit should be 6 minutes or less.

4.4.1.2 Ministry of Interior Regulations

This is the regulation for the building design in Thailand, providing prevention of fire and fire evacuation. Examples of regulations are:

- The stairs must be shown that it can evacuate all the occupants to the exterior of the building within 1 hour.
- There are fire exit paths that connect to every floor, which contains at least 2 exits per floor with evacuating occupants to safety area within 5 minutes.
- There must be no obstructions on the fire exit path from building towards the safety area and the width of exit way should be more than 1.70 m.

4.4.2 Evacuation model

The model of MRT Huai Khwang station was created by VISSIM software using VISWALK module. In this study considers two cases (base case scenario and worst case scenario) at a different number of users. In the base case scenario, it supposes that all fare collection gates and swing gates are opened during emergency situation (Figure 4.31). On the other hand, in the worst case scenario, the electricity might be cut off during the emergency. It is assumed that the fare collection gates do not operate except the swing gate (this gate is normally used for staffs, disable person or person with large luggage, and open manually).



Figure 4.31 Fare collection gates and swing gate

4.4.2.1 The walking speed of pedestrian evacuation

The pedestrian walking speed during evacuation could not be collected at the MRT Huai Khwang station during normal condition. Therefore, in order to obtain the speed during evacuation, the speed data were collected from the experiment by video cameras at Sirindhorn International Institute of Technology. Students were asked to evacuate from the building through the passageway. The time used in evacuation was recorded in order to calculate the evacuation speed.

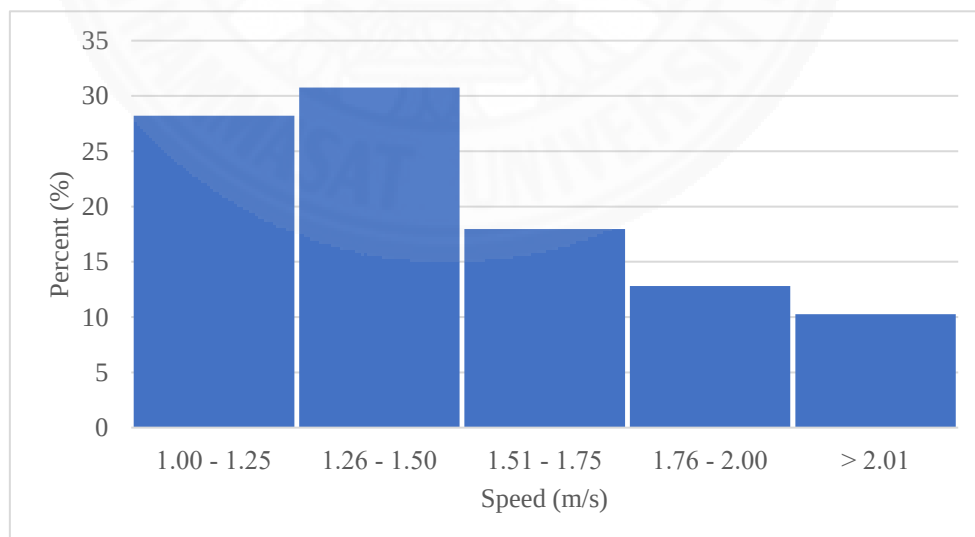


Figure 4.32 The pedestrian evacuation walking speed



Figure 4.33 Measure the walking speed during the evacuation process

Figure 4.32 showed the average pedestrian walking speed during an evacuation is 1.46 m/s. The average walking speed of pedestrians during the rush hour at MRT Huai Khwang station found from the field survey was 1.31 m/s which is lower than the speed of pedestrians during evacuation. In this experiment, because the data were collected from an experiment settings at the university, pedestrian speeds were collected from 61.11% male, 38.89% female and age of 17–19 years.

4.4.3 The result of pedestrian evacuation

In the VISWALK model, the evacuation started at the platform. So the pedestrians should be evacuated from platform to 4 exit corridors. During the evacuation process, escalators and the elevator are not allowed to use because the electricity would be cut for standard security procedure. Some parameters in the simulation models including grid size, speed, relaxation time (τ_j), repulsive force and desired speed at the stair are calibrated to represent the actual situation at this train station. The evacuees move to exits through the shortest path which is calculated from VISWALK. The average evacuation time from 10 simulation runs was used to validate the model. NFPA evacuation time criteria consist of 2 situations as follows: Platform evacuation time should be within 4 minutes or less and the station should be evacuated within 6 minutes or less.

Table 4.19 Evacuation time of both cases

Scenarios	Number of pedestrians in peak 15-min	Evacuation time (min)		
		Platform evacuation ^a (t_1)	Fare gate evacuation (t_2)	Station evacuation ^b (t_3)
		Maximum time	Maximum time	Maximum time
Scenario 1: Base case scenario	1300 ^c	2.30	2.40	4.39
	1400	2.32	2.47	4.53
	1500	2.38	3.01	4.56
	1600	2.46	3.06	5.12
	2000 ^d	3.12	3.37	5.38
Scenario 2: Worst case scenario	1300 ^c	2.31	2.58	4.51
	1400	2.33	3.01	5.00
	1500	2.41	3.19	5.06
	1600	2.51	3.24	5.18
	2000 ^d	3.16	4.01	5.52

^a NFPA-130 evacuation from the platform within 4 minutes or less (t_1)

^b NFPA-130 evacuation to safety area within 6 minutes or less (t_3)

^c Peak 15-min volume in 2019

^d Peak 15-min volume in 2027

The platform evacuation time of both scenarios is close (Table 4.19) due to the fact that all the evacuation conditions are same. However, the fare gates evacuation time and station evacuation time of both scenarios are different due to the assumption of power shut down during emergency. The maximum evacuation time occurred at the stair 1. According to NFPA-130, all of the pedestrians should be evacuated from the platform within 4 minutes or less and the results showed that both scenarios passed the minimum time requirement. The farthest point towards stairs is 40.2 m which is less than the requirement of 91.4 m. In addition, according to the Ministry of Interior regulations, MRT Huai Khawng station meets the requirement that is at least 2 exits in every floor and evacuation should be within 5 minutes.

Table 4.19 showed that the evacuation time to the fare collection gate of 2 scenarios were different. In the worst case scenario, the simulation showed that there exists the bottlenecks at stairs and swing gates. This made the evacuation time increase around 12.04% from the base case scenario.

The distances from the platform to each exit are different. In which pedestrians prefer to use the shortest path. The farthest distance of exits following exit 3 (138 m),

exit 4 (131 m), exit 1 (121 m) and exit 2 (113 m) so, most users select exit 2 (30.20%) following with exit 1 (27.80%), exit 4 (22.13%) and exit 3 (19.88%).

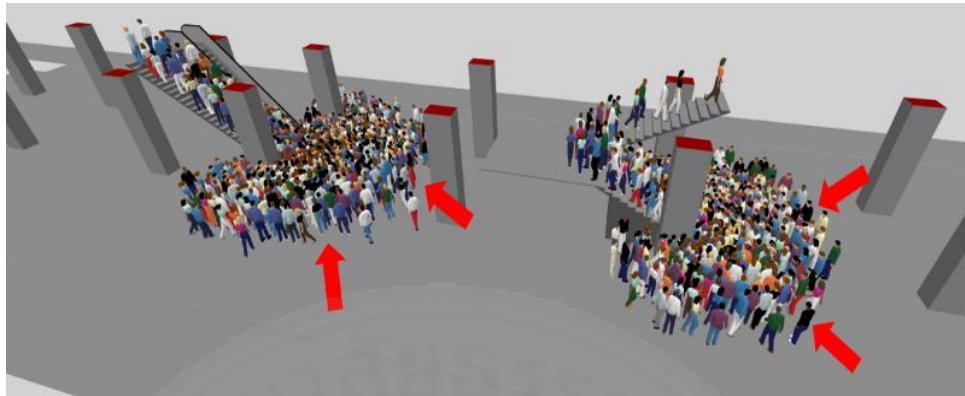


Figure 4.34 Bottleneck at the stairs during an evacuation

4.5 Discussion of results

The results of this study are separated into two situations including the normal situation and the evacuation situation. In addition, the field survey results are important to increase the significance of the simulation model. The discussion was evaluated the results of each part in this study and explained the outcomes from results.

The field survey data of pedestrians flow was collected in MRT Huai Khwang station in the morning at 7.30 am - 8.30 am using 3 days by manual counts and video camera. The results of the survey are separated into five parts. Firstly, facilities and obstacles dimension in MRT Huai Khwang station satisfy the requirement of both local and international standards. The volume of pedestrians shows the maximum pedestrian enter the station (976) from 7.46 am - 8.00 am due to the start time of working at 8.30 am. The proportion of data at the station entrance shows that passengers prefer to use entrance 1 (47.50%) followed by entrance 4 (20.84%), entrance 3 (19.10%) and entrance 2 (12.56%). The results of pedestrian walking speed show the fluctuation of walking speed depend on the period of time. The pedestrian routes showed the pattern of pedestrian movement in MRT Huai Khwang station. Lastly, the queue patterns from video cameras show the queue using the service performs line up one behind one.

After the field survey was conducted, the results were inputted to the pedestrian simulation model in the case study of the normal situation. VISWALK software was applied in this study for parameters calibration to find the suitable parameters for

pedestrian behaviors in train stations. The grid analysis was used to find the minimum error of the pair of parameters by sum square error (SSE). The results of calibrated parameters were classified into four criteria in Table 4.9. Tau (τ) and Lambda (λ) are the parameters that affected the walking speed and the results reveal that if increase the Tau (τ) and Lambda (λ), the walking speed will decrease. The result of calibration shows that Tau (τ) is 0.15 and Lambda (λ) is 0.85 with the SSE of 0.01. The time of pedestrians pass through the bottleneck is affected by Noise and React to N. the results show that if an increase in the React to N, pedestrians will take time to pass through the bottleneck. On the other hand, if increase the Noise, the time of pedestrian pass through the bottleneck will decrease. The optimum value of React to N is 3.00 and Noise is 2.00 with the SSE of 1.69. Grid size and VD affect the number of pedestrians pass through the opposite direction. The results show that if an increase Grid size and VD, the number of pedestrians pass through the opposite direction will increase. The optimum value of Grid size is 2.75 and VD is 2.00 with no error. The waiting time of pedestrians queueing is affected by Queue order and Queue straightness, the results reveal that if increase the Queue order and Queue straightness, the waiting time of pedestrians queueing will decrease. The optimum value of Queue order is 1.00 and Queue straightness is 1 with the SSE of 4.41. The validation of parameters is taken into account to check the error of the different parameter sets including default value, MRTA (2016), Prabhu and Sarkar (2016) and Calibrated parameters in this study. The results show the error of parameter sets by applying the parameters into MRT Sukhumvit station, it found that the minimum error is the calibrated parameters in this study with an average error of 3.88 %.

The pedestrian evacuation model was conducted due to there has been no emergency situation in train station in Thailand. Thus, this model will compare the evacuation time and the standard facilities dimension with the NFPA national standards and Ministry of Interior Regulations to provide the safety in MRT Huai Khwang station. The input data came from the field survey results except for the pedestrian walking speed due to the results of walking speed came from the normal situation. So, the evacuation experiment was conducted to find the evacuation walking speed and the evacuee behaviors by recording video cameras. The parameters for pedestrian

evacuation are calibrated to fit the results from the evacuation experiment. The grid analysis was used to calibrate the parameters similar to the normal situation.

Table 4.20 Calibration criteria in evacuation situation

Calibration criteria	Parameters	Calibrated parameters for pedestrian evacuation
Pedestrian walking speed	Tau (τ)	0.20
	Lambda (λ)	0.60
Flow of pedestrian	Grid size	2.75
	VD	1.00
Time used by pedestrians to pass through the bottleneck	Noise	5.00
	React to N	8.00
Desired speed factor at the stairs	Desired speed factor	55 %

Table 4.20 showed the calibration criteria and calibrated value of pedestrian evacuation. The calibrated value of pedestrian walking speed found the SSE error of 0.09 while the SSE error of the pedestrian pass through the bottleneck is 0.25. The results of pedestrian walking the same and opposite directions are no error. The results of the evacuation experiment reveal that the walking speed of pedestrians will decrease when using the stair. Therefore, the desire speed factor is considered by comparing the time that pedestrians go to the first floor using the stairs. The results reveal that if increase the Desire speed factor, the time of pedestrians using the stairs will decrease. The optimum value of Desire speed factor is 55 % with the SSE of 1.23. The average error of calibrated parameters found on 0.39 % using percent error. According to NFPA-130, the pedestrians should be evacuated out of the station within 6 minutes or less. The results of evacuation time showed that the evacuation time was less than that is required from NFPA-130 standards and the Ministry of Interior Regulations. Moreover, the average travel time drops from 2.46 min (normal condition) to 3.21 min (evacuation, base case scenario) and 3.46 min (evacuation, worst case scenario) due to the congestion at the stairs and high density of passageway similar to the result from the previous study (Shi et al., 2012)

CHAPTER 5

CONCLUSION

This final chapter demonstrates the principle of this study, following the application of simulations and its limitations. In addition, this part discusses the overall research and evaluates the result, including pedestrian behavior and pedestrian evacuation in the simulation model. The fundamental aim of this study consisted of two parts. The first part conducted the survey in the MRT stations (Huai Khwang and Sukhumvit) including the facilities' dimension, volume of pedestrians, detail of the trains, walking speed, pedestrian routes and recording of pedestrian behaviors. In this part, the most critical area is the collecting of pedestrian data for input into the VISSIM/VISWALK software to test the model's reliability. The second part consists of generating the simulation model to represent pedestrian behavior in a railway station in Bangkok. In addition, calibration is the key to provide the parameter sets that display pedestrian behaviors according to survey data. The advantage of the simulation is that it can demonstrate the circumstances virtually, which includes events that have not happened in history. This includes the evacuation in an MRT train station.

The research introduced the significance of railways in Bangkok by the use of statistics from the past several years. This is done to understand the problem of pedestrian behavior and its effects on the movement of a pedestrian in the train station. The literature reviews of this study were separated into three parts including the study of pedestrian flow, pedestrian simulation, and parameter calibration. The previous studies reviewed pedestrian flow in train stations both in Thailand and other countries. This included survey data obtained by using a video camera and the procedure of pedestrian analysis and the facility's design. The simulation of pedestrians was conducted to study the effect of a building on the movement of a pedestrian and developments for the future. Thus, this study adopted the pedestrian simulation model by VISSIM software using module VISWALK to create the pedestrian flow in a train station. The calibration procedure is taken into account to make the model reliable. Several calibration techniques were reviewed to minimize the error between the survey data and results of the simulation. Hence, this study used the grid analysis method to

calibrate the parameters in VISSIM/VISWALK software and finds the error by sum square error (SSE) method. This research is intended to evaluate the parameter sets of pedestrian behavior that represent pedestrian behaviors in a train station. Therefore, the simulation model was developed and calibrated to fit real pedestrian behavior in MRT Huai Khwang station in Chapter 3. The results of the survey in MRT Huai Khwang Station and the value of calibration showed in Chapter 4 follows the comparison of parameter sets with previous studies. Moreover, the application of the simulation was mentioned in terms of evaluation compared with the international standard and the local regulation.

The result of this study was separated into 2 parts. The first part showed the survey data from on-site conditions following the volume of pedestrians, details of the train, pedestrian walking speed, pedestrian routes, time spent using services in the train station and queue patterns by recording with a video camera. Moreover, the survey included details of the facilities and obstacles, labeling them by dimension and obtained using a laser measuring device. In the second part, the simulation model was considered for both cases of application; the normal situation and emergency evacuation. Therefore, calibration is taken into account to ensure the model could visualize the pedestrian behavior. This is done by setting the criteria to find the parameters that affect the walking behavior of pedestrians. Afterward, the calibration method used the grid analysis to find the optimum value of parameters and calculated the error using the sum square error method (SSE).

Table 6.1 Default and calibrated parameters' value

Calibration criteria	Parameters	Default value	Calibrated value	
			Normal situation	Evacuation situation
Pedestrian walking speed	Tau (τ)	0.400	0.150	0.200
	Lambda (λ)	0.176	0.850	0.600
Pedestrian flow	Grid size	5.000	2.750	2.750
	VD	3.000	2.000	1.000
Time used by pedestrians to pass through the bottleneck	Noise	1.200	3.000	5.000
	React to N	8.000	2.000	8.000
Time spent by pedestrians in queues	Queue order	0.700	1.000	0.700
	Queue straightness	0.600	1.000	0.600

Table 6.1 showed that the value of each parameter with different purposes of the study, between the normal situation and emergency evacuation. Thus, the average minimum error was less than 10 percent. The evacuation aimed to consider two cases (base case scenario and worst case scenario) at a different number of users and comparing the data with the National Fire Protection Association (NFPA) standards and Ministry of Interior Regulations in Thailand. The result of the two case scenarios satisfies both the requirements at the peak 15-min volume in 2019 and 2027.

Lastly, due to the lack of literature illustrating pedestrian flow and pedestrian behavior in Thailand, the information about pedestrians' study in Thailand is limited in chapter 2. The duration of the on-site survey is restricted on 3 days per week due to the permission to collect the data from the Mass Rapid Transit Authority of Thailand (MRTA).

There also some limitations of the VISWALK software that lack the parameters related to pedestrian evacuation such as low visibility (smoke of fire), changing paths (block the exit path), and negative emotions (shock or panic). Moreover, the duration of the survey is limited due to the permission of Mass Rapid Transit Authority of Thailand (MRTA).

The recommendation should be increased the duration of the survey to increase the reliability of data. These calibrated parameters are suitable for pedestrian simulation in train stations in Thailand. Thus, the train stations for calibrated parameters should be included three or more levels, queue line at the platform level and enough space for walking of pedestrians. However, care must be taken to other train stations including shop at the concourse level and deadlock at the bottleneck. The parameters were affected by the version of the simulation software so, be careful the updated of the simulation program. In the evacuation in MRT Huai Khwang station, there should be additional emergency exits at the fare collection gate to overcome the ridership growth.

Future studies, the characteristics of pedestrians should be considered such as age, gender, pedestrians with luggages. Thus, the walking speed and the behavior of the pedestrian were affected by the characteristics of the individual pedestrian in both models (normal situation and emergency evacuation). On the other hand, the calibrated parameters applied to solve the problem of pedestrians in transit stations.

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The seal of Thammasat University is a circular emblem. It features a central five-tiered umbrella (parasol) with a flame-like finial. Below the umbrella is a lotus flower. The entire emblem is encircled by a ring containing the university's name in Thai script at the top and 'THAMMASAT UNIVERSITY' in English at the bottom, separated by small floral motifs.

APPENDICES

APPENDIX A

Example of Permission to Collect the Data



 BANGKOK EXPRESSWAY AND METRO		ใบขออนุญาตทำงานทั่วไป		เลขที่ใบอนุญาต 19040046	
ส่วนที่ 1 - การขออนุญาต					
ผู้ควบคุมงาน : BEM-1445: ผู้จัดการแผนกวิศวกรรม (BEM / PIC-BLL+CG-BLL)			รายละเอียดงาน : ตรวจสอบและสังเกตการณ์การเข้าแถวคอยของผู้โดยสาร ด้วยการบันทึกภาพนิ่งและภาพเคลื่อนไหว บริเวณเข็นออกบัตรโดยสาร ขึ้นขบวนขบวน และขึ้นร้านค้า รวมถึงทางเดินภายในสถานี ของสถานีหัวขบวน (HUI) (โดยไม่กีดขวางทางเดินของผู้โดยสาร)		
โทรศัพท์ : 183273 โทรสาร : 183299			วันที่ 22-26 เม.ย.62 ตั้งแต่เวลา 6.30 - 10.00 น. **รายละเอียดตามไฟล์แนบ**		
สถานที่ทำงาน : HUI					
อุปกรณ์ / ระบบที่ต้องการติดตั้ง / พลังงาน / เหตุการณ์ทำงานชั่วคราว ระหว่างงาน ☒ ไม่มี ☐ มี					
อุปกรณ์ / รถไฟฟ้า / สถานการณ์ / บริการอื่น ๆ ที่ต้องการ : ☒ ไม่มี ☐ มี					
วันเข้าทำงาน (สูงสุดไม่เกิน 7 วัน) จาก 22-Apr-2019 ถึง 26-Apr-2019		เวลาเข้าทำงาน จาก 6.30 ถึง 10.00			
ผู้ขออนุญาต : ผู้จัดการแผนกวิศวกรรม		โทรศัพท์ : 183273 โทรสาร : 183299		ลงชื่อผู้ขอ : วันที่ : 09-Apr-2019 เวลา 14:22	
ส่วนที่ 2 - การขออนุญาตให้ปฏิบัติงาน					
การทำงานต้องอยู่ภายใต้การกำกับดูแลตลอดเวลาโดย : ☒ หัวหน้าคณะทำงาน ☐ เจ้าของพื้นที่ ☐ อื่นๆคือ					ใบอนุญาตทำงานเลขที่ BMGW/62/09983
คำสั่งพิเศษ / มาตรการด้านความปลอดภัย / ข้อกำหนดเพิ่มเติม :					
อนุมัติรับเข้าทำงาน จาก 22-Apr-2019 ถึง 26-Apr-2019		อนุมัติเวลาเข้าทำงาน จาก 6.30 ถึง 10.00			
ส่วนงานที่รับผิดชอบ : ☐ ส่วนควบคุมการเดินรถ ☐ ส่วนเจ้าหน้าที่ควบคุมรถ ☒ ส่วนสถานี					
ลงชื่อผู้อนุมัติ : ดร.พล ชูวัชร		ตำแหน่ง : ผู้จัดการ		วันที่ : 10-Apr-2019	
ส่วนที่ 3 - การพิจารณาของเจ้าของพื้นที่					
☐ อนุญาตให้ทำงานได้		☐ ไม่อนุญาตเนื่องจาก		ลงชื่อเจ้าของ ตำแหน่ง / ID : วันที่และเวลา	
ส่วนที่ 4 - การประเมินเหตุการณ์ทำงาน					
ยืนยันงานเสร็จสมบูรณ์ ที่พื้นที่งานกลับสู่สภาพปกติ ปลอดภัยสำหรับการให้บริการได้ตามปกติ ยกเว้นรายการที่ต้องแก้ไข (ถ้ามี) :					
ลงชื่อหัวหน้าคณะทำงาน		วันที่และเวลา :		ลงชื่อเจ้าของพื้นที่ :	
				วันที่และเวลา	



การรถไฟฟ้าขนส่งมวลชนแห่งประเทศไทย

Mass Rapid Transit Authority of Thailand

175 ถ.พระราม 9 แขวงห้วยขวาง เขตห้วยขวาง กรุงเทพฯ 10310

175 Rama IX Road, Huai Khwang, Bangkok 10310

Tel. (662) 716 4000 Fax. (662) 306 0713

FACSIMILE

ATTENTION :	นายสมบัติ กิจจาลักษณ์	FAX NO : 02 354 2020
COMPANY :	บริษัท ทางด่วนและรถไฟฟ้ากรุงเทพ จำกัด (มหาชน)	REF NO : รพม 010/1/ 79
FROM :	นายณัฐภัทร์ อุณหงศา	DATE 3 เมษายน 2562
SUBJECT :	ขอความอนุเคราะห์จัดเจ้าหน้าที่อำนวยความสะดวกแก่คณะนักศึกษาสถาบันเทคโนโลยีนานาชาติสิรินธร มหาวิทยาลัยธรรมศาสตร์	NO. OF PAGE : 1 (INCLUDING THIS PAGE)

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MESSAGE

เรียน นายสมบัติ กิจจาลักษณ์
(กรรมการผู้จัดการ)

ด้วย ภาควิชาวิศวกรรมและเทคโนโลยีโยธา สถาบันเทคโนโลยีนานาชาติสิรินธร มหาวิทยาลัยธรรมศาสตร์ มีความประสงค์ขออนักศึกษา จำนวน 6 คน เข้าสำรวจและเก็บข้อมูลผู้โดยสาร เพื่อทำการวิจัย โดยวิธีตั้งกล้องสำรวจ ณ สถานีรถไฟฟ้าห้วยขวาง โครงการระบบรถไฟฟ้าฟ้ามหานคร สายเฉลิมรัชมงคล ในระหว่างวันที่ 22 - 26 เมษายน 2562 เวลา 06.30 - 12.00 น.

การรถไฟฟ้าขนส่งมวลชนแห่งประเทศไทย (รฟม.) ขอความอนุเคราะห์ บริษัท ทางด่วนและรถไฟฟ้ากรุงเทพ จำกัด (มหาชน) จัดเจ้าหน้าที่อำนวยความสะดวกแก่คณะฯ ตามวันและเวลาดังกล่าว โดย รฟม. ได้มอบหมายให้ นายจิราวัฒน์ หงษ์สิบแปด วิศวกร 5 ฝ่ายปฏิบัติการ โทรศัพท์ 0 2716 4000 ต่อ 6111 เป็นผู้ประสานงานต่อไป

จึงเรียนมาเพื่อโปรดดำเนินการในส่วนที่เกี่ยวข้องต่อไปด้วย จะขอบคุณยิ่ง

(นายณัฐภัทร์ อุณหงศา)

ผู้อำนวยการกองกำกับการเดินรถ
รักษาการแทน ผู้อำนวยการฝ่ายปฏิบัติการ

สำเนาเรียน : นายวิฑูรย์ หทัยรัตน
ผอ.ฟรภ.

(0 2354 2030)
เพื่อโปรดทราบ

BEM					
ICV	2562/ MRT/ ๗๗๑				
Date	3/4/62	Time: 14.30			
Group	Action	Copy	Div	Action	Copy
MD			FRAG		
SD			TOG		
FIN			STG		
OS			DSO	✓	
SCG			HRG		
LEG			ACF		

๗๗๑

แผนการเก็บข้อมูลผู้โดยสาร

วันที่สำรวจ 22-26 เม.ย. 2562

เวลา 6.30-10.00 น.

สถานที่ สถานีหัวขวาง (HUI)

รายละเอียดการสำรวจ

1. เข้าสังเกตการณ์การเข้าแถวคอยของผู้โดยสาร ด้วยการบันทึกภาพนิ่งและภาพเคลื่อนไหว บริเวณขึ้นออกบัตรโดยสาร ชั้นชานชาลา และทางเดินภายในสถานีของสถานีหัวขวาง ตามช่วงเวลาดังนี้ (โดยไม่กีดขวางทางเดินของผู้โดยสาร)

ช่วงเวลาสำรวจ	หมายเหตุ
06.30-10.00	• ทีมสำรวจ ลงสำรวจครั้งละ 6 ท่าน • ทีมสำรวจไม่โดยสารรถไฟฟ้า

2. ทีมงานสำรวจ จำนวน 6 ท่าน (รายชื่อตาม PIC safety brief) ทำการเปิด-ปิด Work และแลกบัตรเพื่อติดในขณะปฏิบัติงานที่สถานีหัวขวาง ก่อน-หลัง ปฏิบัติงานทุกครั้ง
ขอให้ผู้ที่มีรายชื่อใน PIC safety Brief สามารถทำการ เปิด-ปิด Work การปฏิบัติงานได้
3. ทีมงานสำรวจจาก สถาบันเทคโนโลยีนานาชาติสิรินธร ม.ธรรมศาสตร์ (SIIT) :
 - แต่งกายด้วยชุดสุภาพเรียบร้อย สวมกางเกงขายาว (ไม่รัดรูป) และรองเท้าหุ้มส้น (ไม่สวมกางเกงขาสั้นขาสั้น และไม่สวมรองเท้าแตะ)
 - สถาบันเทคโนโลยีนานาชาติสิรินธร ได้จัดบุคลากรลงควบคุมและประสานงานการสำรวจครั้งนี้ ได้แก่ คุณภูวิศ บุญสมภาร เบอร์ติดต่อ 086-889-9394
4. อุปกรณ์

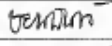
1. กล้องวีดีโอ 4 ตัว พร้อมขาตั้ง
2. แบตสำรอง



	บันทึกการชี้แจงด้านความปลอดภัยโดยหัวหน้าคณะทำงาน (PIC) Person In Charge Safety Briefing Record	SQP
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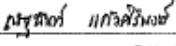
ชื่อ PIC / PIC name	ณัฐนันท์ แก้วศิริพงษ์	หมายเลขบัตร / Badge No.	BEM-1445	บริษัท/ Company	BEM
รายละเอียดงาน/ Description of work	ขออนุมัติการเข้าสำรวจและเก็บข้อมูลผู้โดยสาร ด้วยการบันทึกภาพนิ่งและภาพเคลื่อนไหว บริเวณภายในสถานีด้วยกล้อง (HUI) ของสถาบันเทคโนโลยีนานาชาติสิรินธร ม.ธรรมศาสตร์ (SIIT)		Work permit /Track Possession No.		
วันที่ชี้แจง / Briefing date	9 เม.ย.62	สถานที่ Location : BEM			

รายชื่อผู้เข้าทำงานในพื้นที่ (List of staff)

ลำดับ/ No.	ชื่อ-สกุล Name-Surname	บริษัท Company	ลงชื่อ Signature	วันที่ Date
1	นายภูวิศ บุญสมภาร	SIIT		9 เม.ย.62
2	นายอนุสอน สีสู่ท่า	SIIT		9 เม.ย.62
3	นายชยานันท์ ตั้งชัยสุข	SIIT		9 เม.ย.62
4	นายจิรศักดิ์ จิ	SIIT		9 เม.ย.62
5	นายคณิน พิณจุฑาพันธ์	SIIT		9 เม.ย.62
6	นายณนท ศานติรักษ์	SIIT		9 เม.ย.62

PIC ต้องตรวจสอบความพร้อมเบื้องต้นของผู้เข้าทำงานในพื้นที่ ดังนี้

1. การแต่งกาย เสื้อผ้า ทรงเท้า มีความปลอดภัยต่อการปฏิบัติงาน
2. อุปกรณ์ป้องกันอันตรายส่วนบุคคลครบถ้วน เพียงพอต่อการปฏิบัติงาน
3. ผู้เข้าทำงานต้องมีอายุ 18 ปีขึ้นไป
4. ไม่มีการใช้ยานหรือสิ่งมีคมมาก่อนเข้าปฏิบัติงาน

ลงชื่อ PIC/ PIC signature	
วันที่ /Date	9 เม.ย.62

(ผู้ชี้แจง/instructor)

หมายเหตุ : เมื่อ PIC ลงนามแล้ว กรุณาส่งบันทึกฉบับนี้ให้กับ SC หรือ Landlord (After complete the form please submit to SC / landlord)

หมายเลขเอกสาร : ALL-SQP-FM-036

ฉบับที่แก้ไข C, วันที่มีผลบังคับใช้: 22 เมษายน 59

 BANGKOK EXPRESSWAY AND METRO	ใบขออนุญาตทำงานทั่วไป		เลขที่ใบอนุญาต	
			19060034	
ส่วนที่ 1 - การขออนุญาต				
ผู้ควบคุมงาน : BEM-1445: ฝั่งถนน กว้างศิริพงษ์ (BEM / PIC-BLL+CG-BLL)			รายละเอียดงาน : สำรวจและสังเกตการณ์การเข้าแถวคอยของผู้โดยสาร ด้วยการบันทึกภาพนิ่งและภาพเคลื่อนไหว บริเวณเข็นออกบัตรโดยสาร ขึ้นขบวนขบวน และขึ้นร้านค้า รวมถึงทางเดินภายในสถานี ของสถานีสุขุมวิท (SUK) (โดยไม่เกิดขวางทางเดินของผู้โดยสาร)	
โทรศัพท์ : 183273 โทรสาร : 183299			วันที่ 12-13 มิ.ย.62 ตั้งแต่เวลา 6.30 - 10.30 น. **รายละเอียดตามไฟล์แนบ**	
สถานที่ทำงาน : SUK				
อุปกรณ์ / ระบบที่ต้องการติดตั้ง / พลังงาน / เหตุการณ์ทำงานชั่วคราว ระหว่างงาน ☒ ไม่มี ☐ มี				
อุปกรณ์ / รถไฟฟ้า / ยานพาหนะ / บริการอื่นๆที่ต้องการ : ☒ ไม่มี ☐ มี				
วันเข้าทำงาน (สูงสุดไม่เกิน 7 วัน)			เวลาเข้าทำงาน	
จาก 12-Jun-2019		ถึง 13-Jun-2019	จาก 6.30	ถึง 10.30
ผู้ขออนุมัติ ฝั่งถนน กว้างศิริพงษ์			โทรศัพท์ 183273 โทรสาร 183299	ลงชื่อผู้ขอ : วันที่ : 10-Jun-2019 เวลา 16:47
ส่วนที่ 2 - การอนุมัติให้ปฏิบัติงาน				
การทำงานต้องอยู่ภายใต้การกำกับดูแลตลอดเวลาโดย : ☒ หัวหน้าคณะทำงาน ☐ เจ้าของพื้นที่ ☐ อื่นๆคือ				ใบอนุญาตทำงานเลขที่ BMGW/62/10162
คำสั่งพิเศษ / มาตรการด้านความปลอดภัย / ข้อห้ามเพิ่มเติม :				
อนุมัติวันเข้าทำงาน		อนุมัติเวลาเข้าทำงาน		
จาก 12-Jun-2019 ถึง 13-Jun-2019		จาก 6.30 ถึง 10.30		
ส่วนงานที่รับผิดชอบ : ☐ ส่วนควบคุมการเดินรถ ☐ ส่วนเจ้าหน้าที่ควบคุมรถ ☒ ส่วนสถานี				
ลงชื่อผู้อนุมัติ : ศิริพล จูวรัตน์		ตำแหน่ง : ผู้จัดการ		วันที่ : 10-Jun-2019
ส่วนที่ 3 - การพิจารณาของเจ้าของพื้นที่				
☐ อนุญาตให้ทำงานได้		☐ ไม่อนุญาตเนื่องจาก		ลงชื่อเจ้าของ ตำแหน่ง / ID : วันที่และเวลา
ส่วนที่ 4 - การคืนพื้นที่การทำงาน				
ยืนยันว่างานเสร็จสมบูรณ์ พื้นที่ทำงานกลับสู่สภาพปกติ ปลอดภัยสำหรับการให้บริการได้ตามปกติ ยกเว้นรายการสิ่งต่อไปนี้ (ถ้ามี) :				
ลงชื่อหัวหน้าคณะทำงาน		วันที่และเวลา :		ลงชื่อเจ้าของพื้นที่ :
				วันที่และเวลา



การรถไฟฟ้าขนส่งมวลชนแห่งประเทศไทย

Mass Rapid Transit Authority of Thailand

175 ถ.พระราม 9 แขวงห้วยขวาง เขตห้วยขวาง กรุงเทพฯ 10310

175 Rama IX Road, Huai Khwang, Bangkok 10310

Tel. (662) 716 4000 Fax. (662) 306 0713

ด่วนที่สุด

FACSIMILE

ATTENTION :	นายสมบัติ กิจจาลักษณ์	FAX NO : 02 354 2020
COMPANY :	บริษัท ทางด่วนและรถไฟฟ้ากรุงเทพ จำกัด (มหาชน)	REF NO : รพม 010/1/ 156
FROM :	นายณัฐภัทร์ อุณหงศา	DATE 10 มิถุนายน 2562
SUBJECT :	ขอความอนุเคราะห์อำนวยความสะดวกและให้การสนับสนุนแก่คณะจากสถาบันเทคโนโลยีนานาชาติสิรินธร มหาวิทยาลัยธรรมศาสตร์ในการเก็บข้อมูลผู้โดยสารเพื่อการวิจัย	NO. OF PAGE : 1 (INCLUDING THIS PAGE)

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MESSAGE

เรียน นายสมบัติ กิจจาลักษณ์

(กรรมการผู้จัดการ)

ด้วยภาควิชาวิศวกรรมและเทคโนโลยีโยธา สถาบันเทคโนโลยีนานาชาติสิรินธร มหาวิทยาลัยธรรมศาสตร์ มีความประสงค์ขออนุญาตเข้าเก็บข้อมูลผู้โดยสารสำหรับทำวิจัยในหัวข้อ The Analysis of Pedestrian Station ณ สถานีรถไฟฟ้าสุขุมวิท โครงการระบบรถไฟฟ้ามหานคร สายเฉลิมรัชมงคล ในวันพุธที่ 12 และวันพฤหัสบดีที่ 13 มิถุนายน 2562 เวลา 06.30 - 10.30 น.

การรถไฟฟ้าขนส่งมวลชนแห่งประเทศไทย (รฟม.) ขอความอนุเคราะห์ บริษัท ทางด่วนและรถไฟฟ้ากรุงเทพ จำกัด (มหาชน) อำนวยความสะดวกและให้การสนับสนุนคณะ ตามวันและเวลาดังกล่าว โดย รพม. ได้มอบหมายให้ นายจิราวัฒน์ หงษ์ติบแปด ตำแหน่งวิศวกร 4 ฝ่ายปฏิบัติการ หมายเลขโทรศัพท์ 0 2716 4000 ต่อ 6111 เป็นผู้ประสานงานต่อไป

จึงเรียนมาเพื่อโปรดให้ความอนุเคราะห์ด้วย จะขอบคุณยิ่ง

(นายณัฐภัทร์ อุณหงศา)

ผู้อำนวยการกองกำกับการเดินรถ

รักษาการแทน ผู้อำนวยการฝ่ายปฏิบัติการ

RECEIVED							
9 มิ.ย. / MRT / 0345							
Date	10/6/62	Time	11.00				
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TEB				TOG			
				STG			
				OSG			
				HRG			
				ALF			

แผนการเก็บข้อมูลผู้โดยสาร

วันที่สำรวจ 12-13 มี.ย. 2562

เวลา 6.30-10.30 น.

สถานที่ สถานีสุขุมวิท (SUK)

รายละเอียดการสำรวจ

1. เข้าสังเกตการณ์การเข้าแถวคอยของผู้โดยสาร ด้วยการบันทึกภาพนิ่งและภาพเคลื่อนไหว บริเวณขึ้น-ออกบัตรโดยสาร ชั้นชานชาลา และทางเดินภายในสถานีของสถานีสุขุมวิท ตามช่วงเวลาดังนี้ (โดยไม่กีดขวางทางเดินของผู้โดยสาร)

ช่วงเวลาสำรวจ	หมายเหตุ
06.30-10.30	• ทีมสำรวจ ลงสำรวจครั้งละ 6 ท่าน • ทีมสำรวจ <u>ไม่</u>โดยสารรถไฟฟ้า

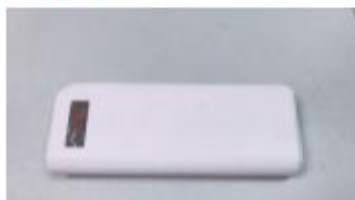
2. ทีมงานสำรวจ จำนวน 6 ท่าน (รายชื่อตาม PIC safety brief) ทำการเปิด-ปิด Work และแลกบัตรเพื่อติดในขณะปฏิบัติงานที่สถานีสุขุมวิท ก่อน-หลัง ปฏิบัติงานทุกครั้ง

****ขอให้ผู้ที่มีรายชื่อใน PIC safety Brief สามารถทำการ เปิด-ปิด Work การปฏิบัติงานได้****

3. ทีมงานสำรวจจาก สถาบันเทคโนโลยีนานาชาติสิรินธร ม.ธรรมศาสตร์ (SIIT) :
 - แต่งกายด้วยชุดสุภาพเรียบร้อย สวมกางเกงขายาว (ไม่รัดรูป) และรองเท้าหุ้มส้น (ไม่สวมกางเกงขาสั้นขาสั้น และไม่สวมรองเท้าแตะ)
 - สถาบันเทคโนโลยีนานาชาติสิรินธร ได้จัดบุคลากรลงควบคุมและประสานงานการสำรวจครั้งนี้ ได้แก่ คุณภูวิศ บุญสมภาร เบอร์ติดต่อ 086-889-9394

4. อุปกรณ์

1. กล้องวีดีโอ 4 ตัว พร้อมขาตั้ง
2. แบตสำรอง

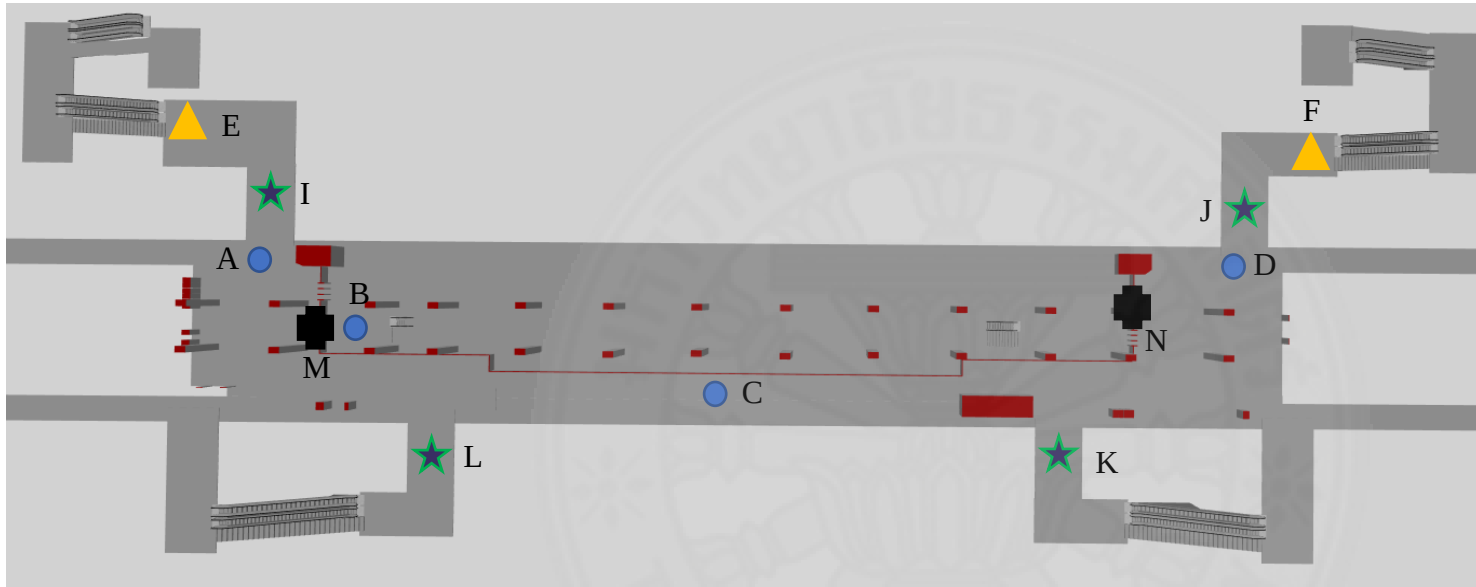


APPENDIX B

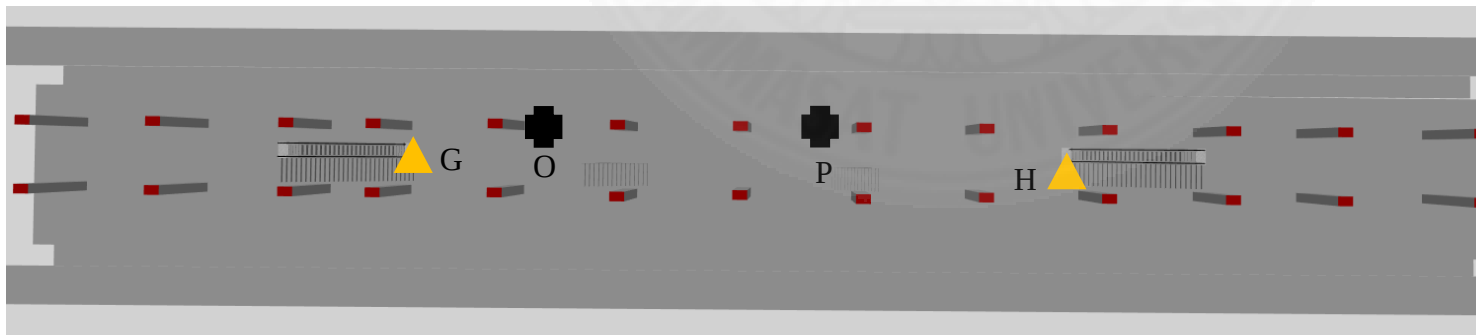
The Results of Each Calibration Criteria



Concourse level



Platform level

**Legend**

- Pedestrian walking speed
- ▲ Time used by pedestrians to pass through the bottleneck
- ★ Flow of pedestrians
- ✖ Time spent by pedestrians in queues

Pedestrian walking speed

The data are average pedestrian walking speed by the random selection of 200 ped/15min. There are 4 observation points of pedestrian walking speed at the concourse level in MRT Huai Khwang station. The distance was 7.1 m. with no obstacles and the time was recorded from the video recording.

	Average walking speed (km/hr)			
	7:31 - 7:45	7:46 - 8:00	8:01 - 8:15	8:16 - 8:30
A	4.84	4.77	4.45	4.71
B	1.67	4.58	4.49	4.58
C	4.91	4.85	4.35	4.73
D	4.05	4.76	4.57	4.53

The results reveal that the pedestrian walking speed is depended on the characteristics of pedestrian such as gender, age, etc.



Screenshot from a video camera at point B

Time used by pedestrians to pass through the bottleneck

The data are average time used by pedestrians to pass through the bottleneck with the number of pedestrians is 40 by recording video cameras at the stairs (points E, F) and escalators (points G, H). There are 4 observation points of the bottleneck at the concourse level and platform level in MRT Huai Khwang station. The width of stairs was 2.0 m and the width of escalators was 1.7 m.

	Average time used by pedestrians to pass through the bottleneck (sec)			
	7:31 - 7:45	7:46 - 8:00	8:01 - 8:15	8:16 - 8:30
E	43	45	41	48
F	46	42	39	45
G	31	34	28	29
H	34	33	31	36

The results reveal that time used by pedestrians to pass through the bottleneck is influenced by the width of the facility.



Screenshot from a video camera at point H

Flow of pedestrian

The data are average flow of pedestrian by separating the number of pedestrians / 15 minutes /m. There are 4 observation points of the flow of pedestrians at 4 entrances on the concourse level in MRT Huai Khwang station.

	Average flow of pedestrians (ped/15min/m)			
	7:31 – 7:45	7:46 – 8:00	8:01 – 8:15	8:16 – 8:30
I	84	97	96	77
J	34	46	34	41
K	38	48	26	32
L	25	26	23	21

The results reveal that the flow of pedestrians is depended on the location of entrances and the size of the study area.



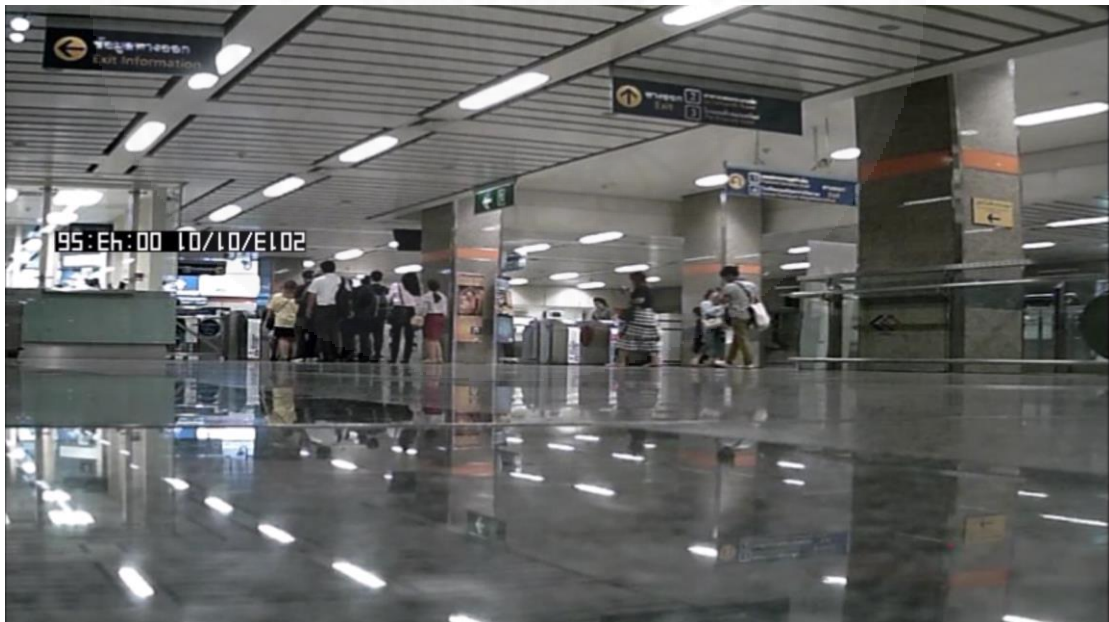
Screenshot from a video camera at point I

Time spent by pedestrians in queues

The data are average time spent by pedestrians in queues from the video cameras. There are 4 observation points of queues at the concourse level and the platform level in MRT Huai Khwang station. The queues of pedestrian are located at the fare collection gates due to the high number of pedestrian.

	Average time spent by pedestrians in queues (sec)			
	7:31 – 7:45	7:46 – 8:00	8:01 – 8:15	8:16 – 8:30
M	96	121	181	152
N	61	98	157	110
O	42	80	76	89
P	60	77	91	87

The results reveal that pedestrians line up in the straight queue and take some time to pass the fare collection gates.



Screenshot from a video camera at point N

APPENDIX C

Example of Parameters Calibration



Calibration using pedestrian walking speed

Initial phase

TAU	LAMBDA	Speed (km/hr)	Sum Square Error
0.10	0.20	4.64	0.49
	0.40	4.65	0.36
	0.60	4.66	0.25
	0.80	4.68	0.09
	1.00	4.67	0.16
0.20	0.20	4.52	3.61
	0.40	4.45	6.76
	0.60	4.49	4.84
	0.80	4.63	0.64
	1.00	4.61	1.00
0.30	0.20	4.22	24.01
	0.40	4.24	22.09
	0.60	4.44	7.44
	0.80	4.45	6.92
	1.00	4.46	6.50
0.40	0.20	4.28	18.51
	0.40	4.29	17.55
	0.60	4.30	16.50
	0.80	4.32	15.43
	1.00	4.33	14.25

Second phase

TAU	LAMBDA	Speed (km/hr)	Sum Square Error
0.10	0.80	4.68	0.09
	0.85	4.68	0.09
	0.90	4.69	0.04
	0.95	4.68	0.09
0.15	0.80	4.69	0.04
	0.85	4.70	0.01
	0.90	4.69	0.04
	0.95	4.68	0.09

Calibration using time used by pedestrians to pass through the bottleneck

Initial phase

REACTTON	NOISE	Time (s)	Sum Square Error
2	1	47.50	20.25
	2	46.40	11.56
	3	44.30	1.69
	4	46.40	11.56
	5	46.80	14.44
4	1	47.60	21.16
	2	46.40	11.56
	3	45.90	8.41
	4	46.50	12.25
	5	48.50	30.25
6	1	49.30	39.69
	2	47.00	16.00
	3	46.90	15.21
	4	47.10	16.81
	5	46.50	12.25
8	1	51.00	64.00
	2	50.30	53.29
	3	49.90	47.61
	4	50.40	54.76
	5	48.30	28.09
10	1	53.30	106.09
	2	52.20	84.64
	3	51.50	72.25
	4	50.80	60.84
	5	51.50	72.25

Second phase

REACTION	NOISE	Time (s)	Sum Square Error
1	2.0	44.90	3.61
	2.5	45.00	4.00
	3.0	45.00	4.00
	3.5	45.00	4.00
	4.0	44.90	3.61
2	2.0	46.40	11.56
	2.5	46.80	14.44
	3.0	44.30	1.69
	3.5	44.90	3.61
	4.0	46.80	14.44
3	2.0	45.50	6.25
	2.5	46.30	10.89
	3.0	45.50	6.25
	3.5	45.00	4.00
	4.0	45.60	6.76

BIOGRAPHY

Name	Mr. Puvit Boonsomparn
Date of Birth	August 24, 1994
Education	2017: Bachelor of Engineering (Civil Engineering and Technology) Sirindhorn International Institute of Technology Thammasat University 2019: Master of Science (Civil Engineering and Technology) Sirindhorn International Institute of Technology Thammasat University

Publications

Boonsomparn, P., & Piantanakulchai, M. (2019). Simulation of Pedestrian Evacuation in the Underground Train Station: A Case Study of MRT Huai Khwang Station. *Proceedings of 7th International Symposium on Advances in Civil and Environmental Engineering Practices for Sustainable Development (ACEPS)* (pp. 173-180). Sri Lanka, Galle: University of Ruhuna