# EMPIRICAL INVESTIGATION OF WALKING SPEED FOR BI-DIRECTIONAL FLOW AT ANGLED-WALKWAY

AIMI SYUHADA BINTI MOHAMED IZHAM

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By

AIMI SYUHADA BINTI MOHAMED IZHAM

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Name of Student: Aimi Syuhada Binti Mohamed Izham

I hereby declare that all corrections and comments made by the supervisor(s)and examiner have been taken into consideration and rectified accordingly.

Signature:

Approved by:

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(Signature of Supervisor)

Date :

Name of Supervisor :

Date :

Approved by:

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(Signature of Examiner)

Name of Examiner :

Date :

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# ABSTRAK

Kelajuan pejalan kaki dipengaruhi oleh faktor-faktor berikut seperti ketumpatan pejalan kaki, lebar jalan, dan sudut jalan. Terdapat banyak kajian penyelidikan yang telah dilakukan untuk menganalisis dinamika pejalan kaki pada aliran satu hala di jalan-jalan yang bersudut. Walau bagaimanapun, kajian mengenai pergerakan pejalan kaki pada aliran dua hala di di jalan-jalan yang bersudut kurang ditekankan. Oleh itu, kajian ini dijalankan untuk menentukan kelajuan berjalan pejalan kaki secara empirikal untuk aliran dua hala di jalan-jalan yang bersudut. Bagi eksperimen ini, 60 orang peserta ditugaskan untuk melakukan pelbagai tugas dalam berjalan kaki di jalan yang lurus, kerana halaju ini digunakan sebagai garis dasar dalam eksperimen ini sebelum para pejalan kaki diminta untuk melintasi sepanjang lebar yang berbeza (1.5m, 2.25m dan 3m) 90 °. Video telah ditangkap dengan menggunakan kamera GoPro dipasang di siling di Dewan Serbaguna, Univeristi Sains Malaysia, Kampus Kejuruteraan yang kemudiannya halaju pejalan kaki ditentukan dengan menjejaki trajektori mereka. Hasil keputusan eksperimen termasuk kelajuan berjalan pejalan kaki mengikut jantina, dan kesan sudut pada tingkah laku pejalan kaki dan penurunan kelajuan apabila menghampiri sudut jalan. Telah didapati bahawa kelajuan berjalan purata perempuan, adalah lebih tinggi dari purata kelajuan berjalan lelaki. Ia diperhatikan bahawa pejalan kaki cenderung berjalan lebih dekat ke sudut dalaman dan didapati pejalan kaki mengurangkan kelajuan mereka ketika menghampiri sudut. Hasilnya amat penting untuk mereka bentuk struktur pejalan kaki dan juga memberi manfaat kepada reka bentuk pelan tindak balas kecemasan.

# ABSTRACT

Pedestrian walking speed is influenced by the following factors such as density of pedestrian, width of walkway, and angle of walkway. There are many research studies that have been done to analyse the pedestrian dynamics on unidirectional pedestrian flows on angled-walkway. However, the study on the movement of crowds on bi-directional flow at the angled-walkway is relatively rare. Therefore, this study is conducted to determine empirically walking speed of pedestrian for bidirectional free flows at angled-walkway. For this experiment, 60 participants are assigned to perform various tasks in walking at straight walkway, as the velocity was used as a baseline to in this experiment before the pedestrians were asked to traverse along different widths (1.5m, 2.25m and 3m) of 90°angled-walkway. The videos have been captured using GoPro Camera mounted on the ceiling at Dewan Serbaguna, Univeristi Sains Malaysia, Engineering Campus which then the velocity of pedestrians was determined by tracking their trajectories. The result includes the walking speed by gender, and the effect of the corner on the behaviour of the pedestrians and their approaching speeds. It was found that that average walking speed of female, is higher than average walking speed of male. It was observed that pedestrian tend to walk closer to the inner corner and the pedestrian to reduce their speed when approaching the corner. The results are of particular importance for designing the structure especially walking at walkway and also beneficial for the design of an emergency response plan.

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background

An angled-walkway is a common geometrical condition that frequently found in all kinds of buildings and pathways. For instance, a corner of the emergency staircase which is usually located at building edges (end of the building), and an angled path facility on walkways. Pedestrian behaviour who is walking at straight and angled-walkway was different. Logically, the velocity of the pedestrians approaching the angled-walkway would be decreasing, as the slow down effect exists in order for them to change directions of walking. This situation will trigger restrictions to pedestrian flow. Therefore, understanding the behaviour of pedestrian behaviour at angled-walkway is important to propose a suitable dimension of pedestrian facilities and emergency response plan.

Angled-walkway is believed could trigger restrictions to pedestrians flow and jammed during rush hour, like at schools. This phenomenon happened when pedestrians tend to move in the same place at the same time. For instance, during recess time, pedestrians tend to move simultaneously out from the classes which will results in jamming at that place. The situation might become worst when the pedestrian flow is stuck at complex geometrical condition like an-angled-walkway and considering unidirectional and bidirectional flow.

Many recent studies focus in how the unidirectional flow movements could affect the velocity of the pedestrians. However, study of angled-walkway effects on pedestrian density-velocity relationship (fundamental diagram) and evacuation behaviour, which considering bidirectional flow is comparatively rare. This study is focused on determining the walking speed of pedestrian for bidirectional free flows at angled-walkway facility at angle 90° with different width of pathway (1.5m, 2.25m, 3m). An experiment were conducted which involved a maximum of 60 pedestrians represented by students of Universiti Sains Malaysia. They were asked to walk in free movement of bidirectional flow on designated walkways. The movements of pedestrians were video recorded and the macroscopic quantity of speed was then calculated.

The results from this research are useful database and tool for the design and dimensioning of future pedestrian facilities which involved angled-walkway geometries in all kinds of building. Moreover, precise quantitative empirical data from this research can be a fundamental data for understanding crowd behaviour for future crowd management strategies.

## 1.2 Problem statement

Angled-walkway is a complex geometrical or facilities that may exist in the buildings or outside of the buildings such as park. The angled-walkway could trigger restrictions to pedestrian flow, thus causing jam during rush hour. Jamming phenomenon might occur at the angled-walkway, governing factors such as the width of walkway, density of pedestrian, structure of building, psychological effect and so on. The capacity decreases when the angle increases, with the bidirectional situation being the worst case scenario.

Many recent studies focused on straight walkway and bottleneck effects. The parameters such as speed, density and flow were determined for this study. However, study on the effect of walking speed of walkway at different angles is comparatively rare. The angled-walkway should be further studied to improve the quality and effectiveness of the design of walking facility.

Besides that, this study is focused on bidirectional flow. Many recent studies focus on unidirectional flow instead of bidirectional flow. The bidirectional flow which involves two way movement will introduce more complex movement which possibly, pedestrians will reduce their speeds at the corner.

## 1.3 Objectives

The objectives in this study are:

i. To determine empirically the walking speed of pedestrian for bidirectional flows at angled-walkway facility by considering different widths of 90° angled-walkway (1.5 m, 2.25 m and 3 m)

ii. To quantify the walking speed of the pedestrians when approaching the corner

## 1.4 Scope of work

The study area for this research is at pedestrian walkways where it could be inside of the buildings and outside of the buildings which at parks, for instance. The width of walkway manipulated at different widths of walkway (1.5 m, 2.25 m and 3 m). Moreover, this study focused on the bidirectional flow instead of unidirectional flow. The experiment was done on three different widths of 90° angled-walkway (1.5 m, 2.25 m and 3 m). This study focused on maximum 60 pedestrians which demonstrates the density of the pedestrians at the angled-walkway

## 1.5 Significance of study

The importance and benefit of this study such as:

1. The typical form of fundamental diagram of bidirectional flow for an angled-walkway facility is produced based on empirical results obtained from the experiment.
2. The obtained results presents some specific applications to safety analysis in public buildings and crowd risk analysis and safety engineering.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Overview

This study is applicable to understand the pedestrian behaviour during evacuation as it is useful for future building design, pedestrian facilities design, safety assessment and management of emergency walkway. Nowadays, buildings have accommodate many complex structure as to show the modern and aesthetical value. For instance, stairs, crossings, T-junctions, corners, and so on. Pedestrians might have difficulties to walk through all of the facilities mentioned as their movement was restricted and slowed as they need to change their direction of walking. The dynamics of pedestrians' stream was more complex and no wonder the uncertain behaviour and non-adaptive behaviour of pedestrians may emerge during an emergency situation. Therefore, the central problems in pedestrian dynamics need to be addressed. To bring the betterment of the pedestrian facilities design, many models have been built to analyse the pedestrian behaviour. Throughout the models, the crowd phenomena is reproduced qualitatively. Before using a model to predict quantitative results such as evacuation time, it needs to be calibrated thoroughly and validated by using empirical data (Boltes et al., 2014; Zhang et al., 2011).

This chapter presents the overview of the pedestrian behaviour when walking in a complex walkway. Furthermore, this chapter show the recent research which interrelated to the pedestrian dynamic both by experiment and modelling.

## 2.2 Pedestrian walking behaviour

Understanding pedestrian walking characteristics is important for the planning and design of the pedestrian facilities as well as for emergency evacuations. The pedestrian walking behaviour of each person may varies as the characteristics of pedestrian varies. Pedestrian are more likely to change their speed and direction when they interact with changes in environment or infrastructure ahead of them. The situation becomes more complex when the group of pedestrians share a same space of location, and the directions of the pedestrians are varies (involving crossing, turning and merging movements and so on). Therefore, it is crucial for the designers to plan the suitable design of the walkway so that to ensure the safety of the pedestrians and to make sure that their comfort are guaranteed when using the pedestrian facilities.

Many recent studies have been carried out to investigate the crowd characteristics. According to (Xiaomeng Shi et al., 2015) the pedestrian walking behaviour will gives big impact to the operational features of crowd flows. Therefore, it is crucial to know the impact of the individual walking characteristics to perform future design of the pedestrian facilities. The study also show that the pedestrian movement behaviours were categorized based on movement dimension and direction of pedestrian flows.

According to (Daamen and Hoogendoorn, 2003), the walking speed of the pedestrian can be affected by several reasons such as the personal characteristics of pedestrians such as age, gender, size, health, and so on. Moreover, characteristics of the trip such as walking purpose, route familiarity, luggage, and trip length may affect the walking speed of the pedestrians. Next, properties of the infrastructure such as type, grade, attractiveness of environment, shelter, and finally environmental characteristics such as ambient, and weather conditions may also affect the walking speed of the pedestrians. Besides the exogenous factors, the walking speed also depends on the pedestrian density.

In another research by (Guo et al., 2012) on walking behaviour of pedestrian groups in the Merchandise Streets, it is stated that almost all studies about human crowd aim at isolated individuals having their own desired speed and direction of motion, but ignore the relationship between the pedestrians. However, most pedestrian in Merchandise Street move in group, such as friends, couple or family. Therefore the study is used to analyse the organisation of pedestrian social groups under the effect of stores along the street by using the basic social force model. In the conclusion, it is found that the collective behaviour is impacted by two ingredients: the other members in the same group and the stores along the street. The pattern of the walking group depends on whether the group members prefer in-group communication or tend to browse the stores. When the group members solely consider the stores, each member of the 2-member group walks like one behind the other; the pattern of 4-member group seems like 2-member groups moving together. The two important properties of the group also affect the aggregated speed, especially for the widely observed 2-memner group. The result is useful to traffic management and safety control, especially for the design of public infrastructure.

(M. Dabbs and A. Stokes, 1975) found that pedestrians tend to give space to other pedestrians. The results show that group of pedestrians will obtain larger space than individuals, pedestrians grant more space to approaching male pedestrians than to female pedestrians. Moreover, women pedestrians was given more space compared to man pedestrians; and attractive women will tend to gain to more spaces than unattractive women.

Another research on group behaviour is by (Meng et al., 2009) discovered that due to no companions distracted, single individuals can pursuit freely their desired speed. Therefore, the speed of pedestrian in group is different from the other individual pedestrian. Individual speed is affected by many factors such as age, sex, body height, stamina and mobility impairments etc. However it is more complex for individuals in group, and the speeds of individuals in groups are the result of interaction and compromise of their group. At the end of the research, human gregarious social characteristic is analysed and the result is concluded. Pedestrian group is complex. Current model about group is relatively simple, and some improvements are needed to further study: 1) Present a detail and uniform pedestrian group and speed function; 2) The evolvement of group alignment in different situation; 3) Quantitatively modelling group dynamic in pedestrian traffic situation.

Based on the previous research studies, it can be concluded that study on the crowd behaviour is really crucial as pedestrian is a complex mechanism and need more research both qualitatively and quantitatively for the benefit in future design of structure and also for better evacuation planning.

## 2.3 Building walkway facilities (Corner, T-shaped and straight walkway)

Designing a walkway might seem like a fairly simple job, but in reality there are a lot of difficulties involved. Research from the California Department of Civil and Environmental Engineering indicates that there are three different types of comfort that comes into play for pedestrians - physical, psychological, and physiological. Physical comfort refers to simply walking easily without needing to exert much effort; meanwhile psychological comfort is a matter of each walk being logistically easy.

Finally, physiological comfort is about the absence of stress. Therefore, it is crucial for engineers to take measure on empirically study of pedestrian walking behaviour at the building walkway facilities especially when it comes to certain situation where density of pedestrian is high and the capability of the facilities to support and provide efficient time and space to others.

Lots of researchers have been studied on several types of facilities such as (Zhang et al., 2011) with their research on empirically study of turning and merging of pedestrian streams in T-junction. A series of well-controlled experiment was set up. The study focuses on the Voronoi method, where the density distribution can be assigned to each pedestrian. For both T-junction and at corner, they choose three different regions, in front merging (left and right) and behind merging. Result are carried out and it is shown that at T-junction, the fundamental diagram of two branches, in front merging, left and right, match well. However at the same density, the velocity in front of the branches is significantly lower than that measured behind the merging of the streams. This discrepancy becomes more distinct in the relation between density and specific flow. Thus, there is no unique fundamental diagram describing the relation between velocity and density for the complete system. Due to discrepancy, the result has been compared with the data at the corner to check whether the merging or the turning is responsible for the differences. It is shown that fundamental diagram of the stream in front and behind corner agree well and no difference is identified. They are also in accordance with that from T-junction flow behind the merging.

A research was carried out on studying the scaling of pedestrian channel flow with a bottleneck by (Tajima et al., 2001). For this research, the study covered dynamical phase transition and scaling behaviour of pedestrian channel flow at a bottleneck under an open boundary condition. The pedestrian channel flow is simulated at a bottleneck by using the lattice-gas model of biased random walkers. The flow rate of pedestrian is calculated by varying the width of bottleneck. The dependence of flow rate on density is shown for various bottleneck widths. From the experiment, it is found that dynamical phase transition from the free flow to the choking flow at a critical density. Besides, it is found that the flow rate of pedestrian exhibits the scaling law.

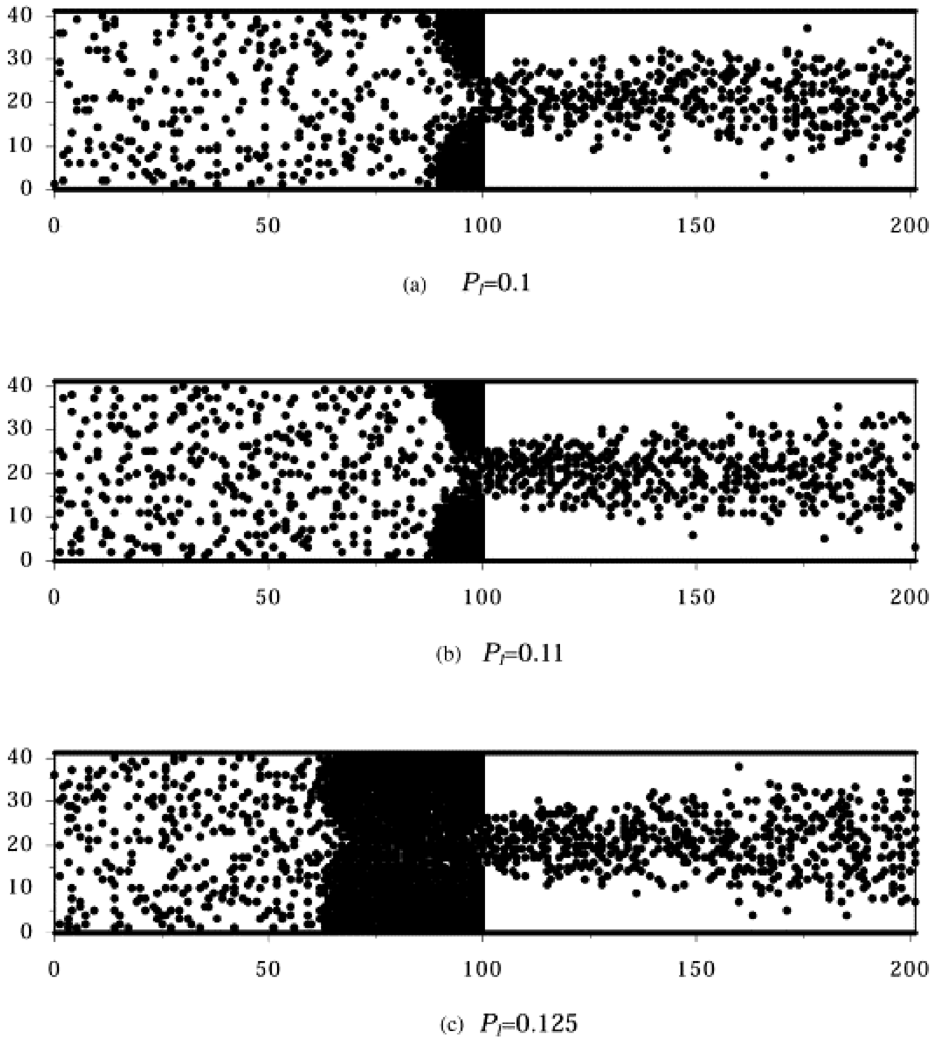



Figure 2.3.1: Typical patterns at T=1000 formed by walkers going through the bottleneck. (a) The pattern at the critical density. (c) The pattern of the saturated flow above the critical density.

Another research studying on bottleneck effect is by (Zhang and Seyfreid, 2014). They quantified bottleneck effects for different type of facilities. As conclusion, it is shown that the restriction effect of a short narrowing on pedestrian flow is smaller than that of long narrowing. In other word, the capacity of facility depends on the length of its narrowing. Narrowing. Furthermore, the appearance of corner leads to turning behaviour which reduced the effective width of walkway and forms a bottleneck. The different capacities indicate that no unique density-flow relationship can be applied to facilities with different kind of narrowing or geometry. Since the supplies of pedestrians especially at congested station in each scenario are different, further data are still needed to check the capacities of the facility.

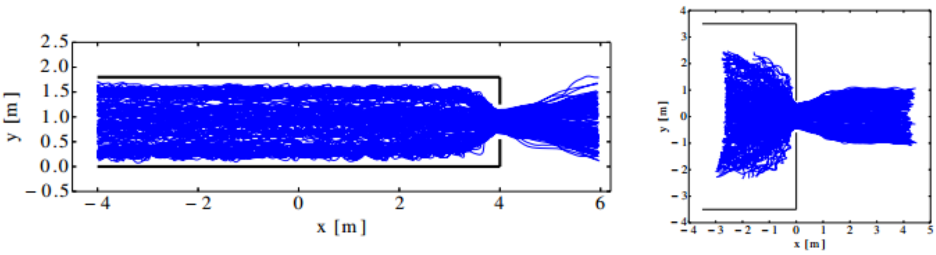



Figure 2.3.2: Pedestrian passing a short narrowing

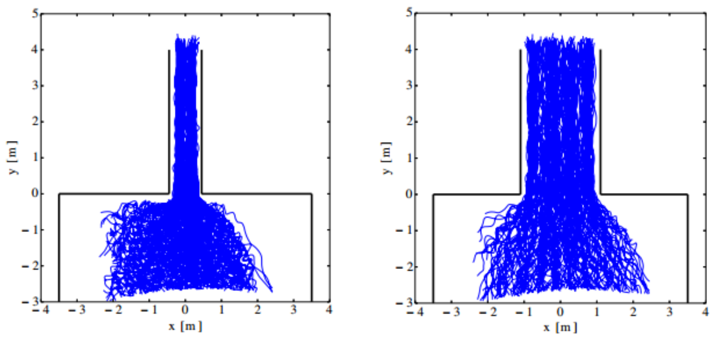



Figure 2.3.3: Pedestrian passing a long narrowing

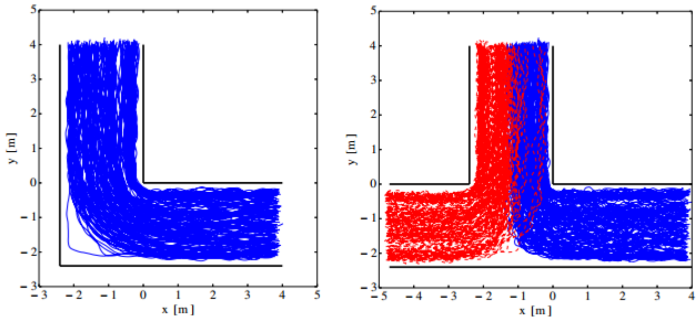



Figure 2.3.4: Pedestrian passing around a corner and T-junction

## 2.4 Bi-directional flows at angled-walkway facilities

Research on Dias et al. (2013), discusses on the human behaviour when walking through angled-walkways. The pedestrians were asked to walk at normal and fast walking speed at 45°, 90°, 60° and 135° angled-walkway. The results on the trajectories of the pedestrians showed that they tend to move into the corner as the route was the shortest path to reach their destination. It was also found that this behaviour will cause additional delay when pedestrians traversed through angled-walkway. This reduction in velocity happens as outer pedestrian tend to move into the corner and this movement will block the movement of pedestrian which has already walk near the corner. Moreover, this paper also found that the walking speed of the pedestrian decreases when the angle of the corner increased. It was also found that pedestrians tend to reduce their velocity when approaching the corner.

A research by (Liu et al., 2014) had done a study on pedestrian counter-flow through bottlenecks. The study focuses on the influence of bottleneck width and directional flow ratio. The lane formation that occurred during the experiment showed that pedestrians’ tend to follow behind the pedestrian which walk in front of them and tend to avoid the pedestrian that oppose them. By analysing the effect of the bottleneck's width on the velocity of the pedestrians, it was found that the wider the bottleneck, the less passing time it takes.

### 2.5 Walking speed

Walking speed of pedestrian is crucial element for safety purpose and also effectiveness in designing the structure. Definitions of macroscopic variables are relatively straightforward in unidirectional in vehicular traffic flow. But it is more complicated to measure these variables in pedestrian traffic flow due to pedestrians' multi-dimensional movements. Generally, speed is defined as the rate of motion expressed as distance per unit time (Highway Capacity Manual, 2000). In terms of pedestrian, pedestrian speed is the average pedestrian walking speed, generally expressed in units of meters per second (Tom, 2014).

Federal Highway Administration (FHWA) Manual on Uniform Traffic Control Devices for Streets and Highways includes a walking speed of 1.2 m/s and Highway Capacity Manual includes pedestrian walking speed depends on the proportion of elderly pedestrians (65 years of age and older) in the walking population. If 0 to 20 percent of pedestrians are elderly, a walking speed of 1.2 m/s is recommended for computation of walkways (Fitzpatrick et al. 2006). Based on FHWA's manual and Highway Capacity Manual 2000, both agree that 1.2 m/s is the walking speed for adults pedestrian. Therefore, this study will use 1.2 m/s as a based speed for experimental analysis.

In walking speed, speed percentiles are tools used to determine effective and adequate speed limits. For example, 85$^{th}$ percentile speeds are used in setting speed limits and for evaluating the effectiveness of safety countermeasures, and 15$^{th}$

percentile speeds are used for establishing typical walking speeds for traffic signal timing (Hou et al. 2012). Another percentile that is used to determine the effectiveness of speed limit is $50^{th}$ percentiles. The $50^{th}$ percentiles is the median speed of the observed data set. This percentile represents the speed at which half of the observed pedestrians are below and half of the observed pedestrians are above.

Walking speed is a key input for various traffic engineering applications. Although the general practice is to use a walking speed of 1.2 m/s when signalized intersections are designed for pedestrians, it is well known that as people age they walk slower (Montufutar et al., 2007). This paper presented the results of research conducted in Winnipeg, Manitoba, Canada, to investigate the walking speeds of older and younger pedestrians at signalized intersections in the winter and the summer. A total of 1,792 records were collected over a period 18 months throughout the city to understand the difference between the normal and the crossing at their normal walking speeds of pedestrians at signalized intersections, as well as to determine the effect of seasonality on walking speed, taking into account age and gender. This research found that even when younger pedestrians are able to complete the crossing at their normal walking speed, they choose to cross at faster speed. The reason for this is not obvious, but if a person does not feel confident enough to increase the abnormal walking speed to cross the street (as may be the case with older pedestrians), he or she may choose to avoid using the facility.

Pedestrian walk differently, on different types of facilities. Walking speeds are governed not only by the width of the facility but also by age and gender, land uses, temporal variations, cell phone usage, carrying baggage while walking, and movement in groups. Another research on walking speed of pedestrian is by (Rastogi et al., 2012). This paper discusses development of adjustment factors for effective design of pedestrian facilities on the basis of pedestrian walking speeds on three types of facilities. The study find that males walk generally faster than females irrespective of facility type. However, speeds of male pedestrians are more influenced by width of facility than those of females. Under varying effects, the speeds of female stabilize faster than male pedestrians. Younger adults show continuously changing behaviour with a change in the width of the facility, whereas older pedestrians show stabilizing behaviour across the facilities. The effect of grouping by age is more pronounced by younger adults, and effect of the width of the facility pronounced on older pedestrians.

Higher group sizes cause high reduction in walking speed irrespective of type of facility. Splitting a larger group was shown to result in the increase in the walking speeds of these groups. Groups are walking slower than the individual pedestrians.

# CHAPTER 3

# METHODOLOGY

## 3.1 Background

The process of determination of the walking speed of the pedestrians is described further in this chapter. Research activities are divided into two parts which is experimental based study and numerical simulation. This research is fully dependent on the experiment analysis data.

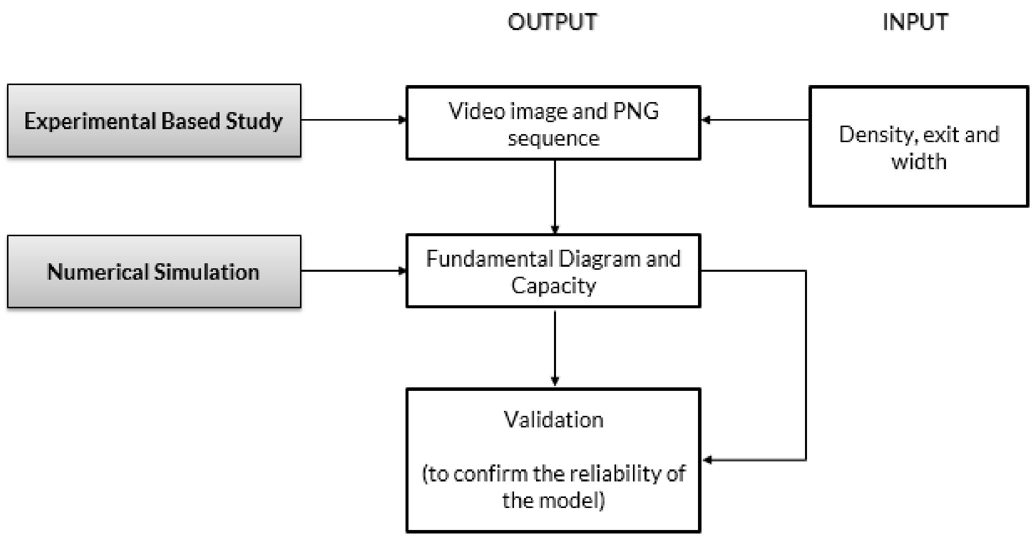



Figure 3.1.1: Methodology of the research activities

For this research, the study area was located at inside of the buildings which was at Dewan Serbaguna, Universiti Sains Malaysia, Engineering Campus. The pathway in the buildings can be various shapes but the angled corner is highlighted in this experiment. The width of the pathway was manipulated by three different widths. (1.5

m, 2.25 m and 3 m). 2.25 meters width is as accordance to the Uniform Building By Laws 1984. Furthermore, various range of ages, which students and staff members are picked to conduct this experiment to create real life situation and thus producing more accurate data.

Figure 3.1.2: Angled-walkway at School of Civil Engineering Campus, Universiti Sains Malaysia

The aim for this study is to determine the walking speed of pedestrian. This study is based on experimental study and numerical simulation. From Figure 3.1.1, it can be seen that this analysis consists of experiment setup, video data gathering and video data analysis. The experiment is conducted first to obtain the empirical data which is the walking speed of the pedestrians. Next, the empirical data is validated using Autodesk MAYA Software and HBS simulator.

## 3.2 Experiment setup

This experiment was conducted at Dewan Serbaguna, Engineering Campus, Universiti Sains Malaysia (USM). The walkway facility which consists of straight walkway and angled-walkway is built .The parameters used during experiment are different widths of 90° angled-walkway by considering different density of pedestrian.

Pedestrians are represented by a maximum of 60 people including male and female students of Engineering Campus, USM. The pedestrians consist of 41 females and 19 males. Before the experiment started, the participants were required to register. White shirt, cap with numbering and personal information form are given during the registration. There are 30 pedestrians wore red caps and the other 30 pedestrians wore blue caps. Red caps indicate pedestrian who move from waiting room 1 and blue caps indicate pedestrian who move from waiting room 2. White T-shirt is used so that pedestrian can be seen without occlusion at any time. Moreover, numbering is given to be put on top of their caps so that pedestrian can be easily identified during tracking process.

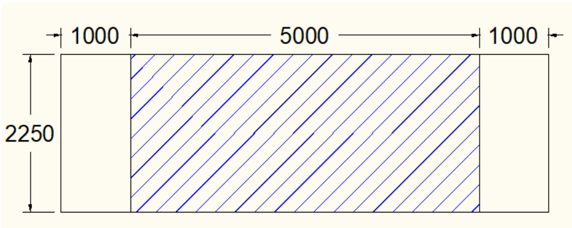
The pedestrians are asked to fill up their weight and height in a form. The weight and height of each pedestrian are measured on the day of experiment using weighing balance and measuring tape. Each pedestrian was asked to move freely three times forth and back along 5 meters length distance for a straight line walkway and the time taken was measured using stopwatch.

Next, the pedestrians were instructed to walk in a 90° angled-walkway to determine the average velocity of the pedestrians walking in an angled-walkway. For this study, the task performed is bi-directional flow. Pedestrians are placed in waiting rooms at one ends of the corner. From both waiting rooms, two streams of pedestrians move towards each other. The inflow rates for this experiment was set homogeneous for all runs. To regulate the walking speed of pedestrian, the width of the walkway was adjusted to three different width of walkway (1.5 m, 2.25 m and 3 m). Different numbers of pedestrian which is 1, 15, 30 and 60 pedestrians used in this experiment. A total of 9 tasks have been carried out and each task indicate different variables such as the pedestrians' density and width of angled-walkway.

Distance is a constant variable. In this study, 5 m length is used to determine the walking speed of pedestrian at straight walkway while 7 m was used for the angled-walkway. The straight walkway used is 5 m length as it is enough for the pedestrian to stabilize the walking speed in straight walkway. The length of angled-walkway is 7m, longer than the straight walkway as the complex geometrical walkway was an obstruction variables so that pedestrians can stabilize their walking speed. One meter length is provided at entry of each walkway as an indicator of the starting point for the pedestrian before entering the evacuation area. One meter length before exit also was also provided to warn the pedestrian that they are going to exit the measurement area indicating the finishing line of walkway. The measurement area is referring to the area which were highlighted in figures below.

The experiment was conducted by instructing the pedestrians to walk in a straight and angled-walkway and the time taken for the each pedestrian to start walking from the enter line to the exit line is measured manually using stopwatch. Then, the time taken for each pedestrian that is taken up using stopwatch is compared with the computer timing method as to validate the data. The difference should be less than 5% for all tasks given to make sure that the experiment can be used to track the pedestrian trajectories.

Time is the total time needed for each pedestrian passing through the measurement area. In this study, the measurement area is also a constant variable. The length is considered in the measurement area is 7 m. The measurement area is marked within the corner area as to determine the effect of corner walkway to the walking speed of pedestrian. The shaded area (Figures 3.2.1, 3.2.2, 3.24, 3.26) indicate the area which the reduction of velocity of the pedestrian will be analysed. The area is estimated by taking the area to be concerned plus half the width of the walkway due to the difference of the width of walkway.




Unit = mm

Figure 3.2.1: The layout of the straight walkway facility with width of 2.25 meters

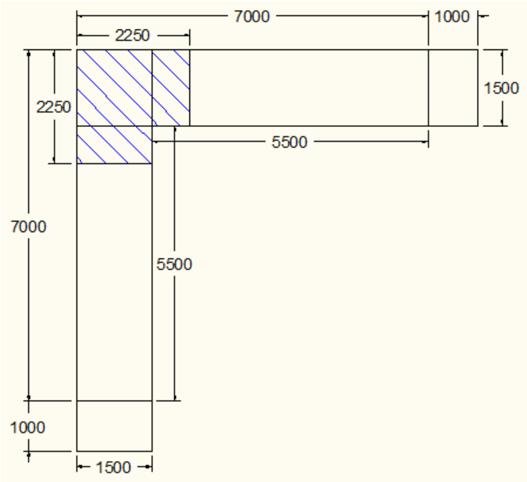



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Figure 3.2.2: The layout of 90° walkway with width of 1.5 meters

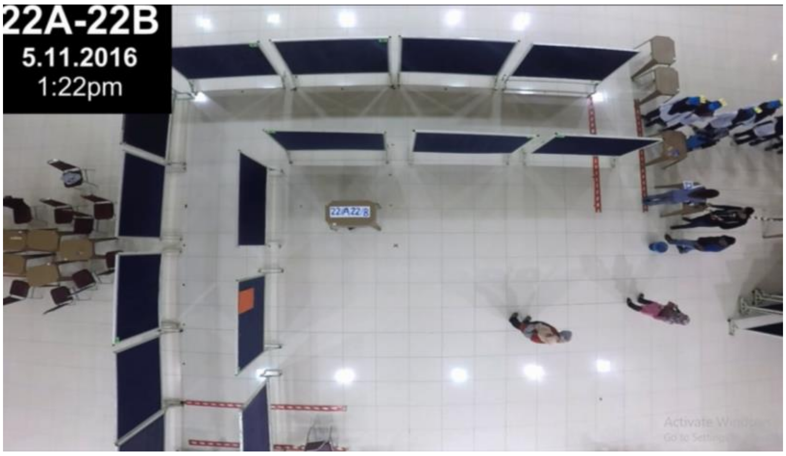
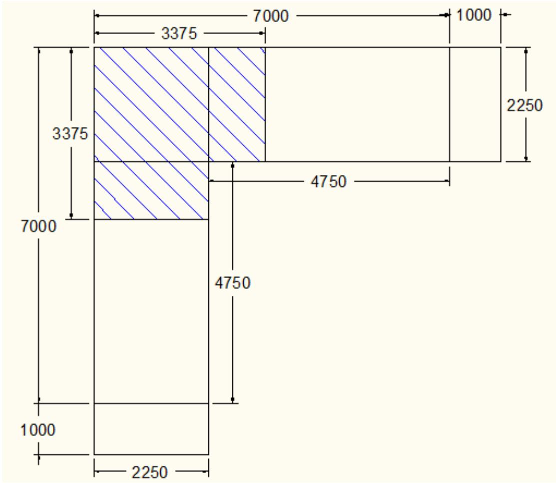



Figure 3.2.3: 90° angled-walkway with width of 1.5 metres




Unit = mm

Figure 3.2.4: The layout of 90° walkway with width of 2.25 meters

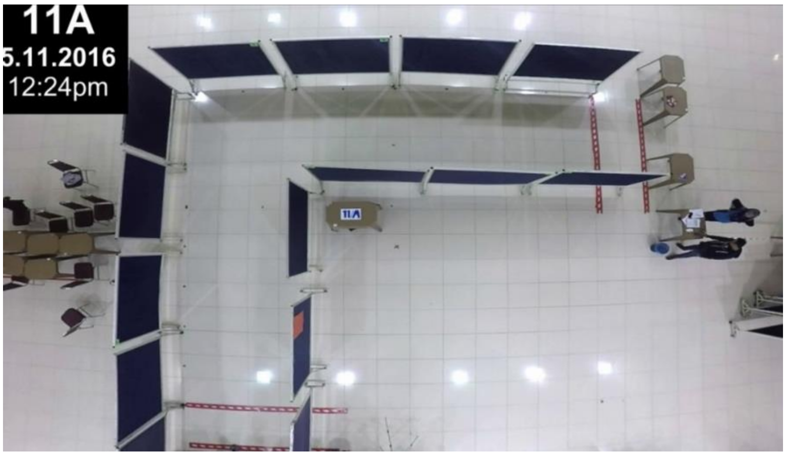
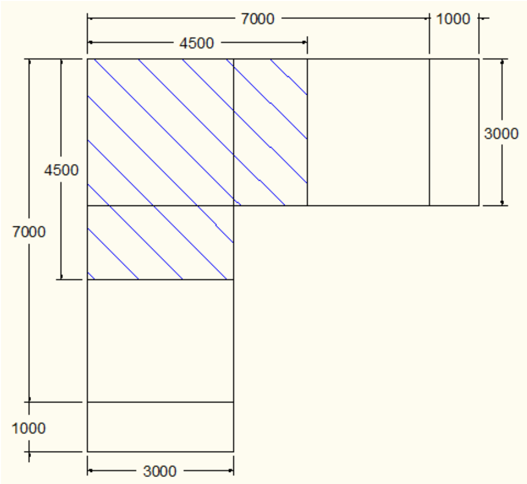



Figure 3.2.5: 90° angled-walkway with width of 2.25 metres




Unit = mm

Figure 3.2.6: The Layout of 90° walkway with width of 3 meters


Figure 3.2.7: 90° angled-walkway with width of 3 metres

## 3.3 Average walking speed

Pedestrian speed is the average speed generally expressed in unit metres per second (Highway Capacity Manual, 2000). The variables considered in this experiment includes the width of the angled-walkway and the density of the bidirectional movement of the pedestrians. The time taken for the pedestrians to walk in a straight walkway is referred as a baseline to compare with the time taken for the pedestrians to walk in an angled-walkway.

## 3.4 Video data gathering

A GoPro Hero 5 Black (GoPro) was used to record every pedestrian movement throughout the experiment session. A GoPro was mounted on the rack of the ceiling of the hall at 7.05 meters from the floor to cover the whole region of the corner during the run of experiments to record the movement of pedestrians. Two waiting rooms had been provided at the end of both sides of the walkway to allow the pedestrians to get ready for the movements. The video is recorded starting from the first pedestrian entering the walkway to the last pedestrian walking out from the walkway. Since the experiment is conducted with the presence of variables, there are about 15 videos with different levels on density of pedestrian and different widths of walkway.

## 3.5 Video data analysis

Video processing was conducted in this study to collect the data as it is considered as the economical technology that can capture all of the movements of each of the pedestrians, fast and efficient.

Video analysis was performed in three stages: (i) conversion from video image to image sequence; (ii) track of pedestrians' trajectories; (iii) determination of average walking velocity

### 3.5.1 Conversion from video image to image sequence

Video image was converted to image sequence in PNG format using Adobe After Effects CS4 with the frame rate of 25 fps;