ANALYSIS OF WALKING VELOCITY OF PEDESTRIAN WALKING THROUGH ANGLED-CORRIDOR BASED ON SPATIAL TRAJECTORIES – A BIDIRECTIONAL SCENARIO

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LIST OF ABBREVIATIONS

AE	Adobe After Effect
HBS	Human Behaviour Simulator
MAYA	Autodesk® MAYA® 2016
NOP	Number of Pedestrian
UBBL	Uniform Building by Law
FHWA	Federal Highway Administration

ANALISIS KELAJUAN PENJALAN KAKI MELALUI KORIDOR BERSUDUT BERDASARKAN LINTASAN RUANG – SENARIO DUA HALA

ABSTRAK

Koridor dapat digambarkan sebagai laluan panjang yang digunakan untuk laluan masuk dan keluar di antara bangunan. Kebelakangan ini, koridor bersudut banyak digunapakai untuk mereka bentuk jalan masuk dan jalan keluar di kemudahan awam. Koridor bersudut adalah jalan antara bangunan atau di dalam bangunan yang mempunyai sudut atau membengkok di antara hujung koridor. Biasanya, pejalan kaki cenderung memperlahankan pergerakan apabila menghampiri koridor bersudut. Disertasi ini fokus kepada pengaruh koridor bersudut pada penjalan kaki dalam situasi dua arah. Kajian ini bertujuan untuk mengenalpasti denai pejalan kaki yang berjalan melalui koridor bersudut (60°, 90°, dan 135°) dalam aliran dua hala, seterusnya untuk menganalisis halaju berjalan pejalan kaki. Untuk mencapai objektif, eksperimen berjalan di koridor bersudut dijalankan di Dewan Serbaguna, Kampus Kejuruteraan, Universiti Sains Malaysia, selama dua hari berturut-turut. Tiga koridor bersudut (60°, 90°, dan 135°) dibina dan senario 1 kepada 1, 15 kepada 15, dan 30 kepada 30 digunakan untuk mencipta situasi dua arah. Semasa eksperimen, para peserta diminta berjalan secara bebas di koridor bersudut. Kamera GoPro digunakan untuk merakam denai pejalan kaki, yang digunakan untuk tujuan penjejakan dan analisis. Hasilnya, denai pejalan kaki dalam ruang diperhatikan dan didapati bahawa dari segi koridor bersudut yang berbeza, pejalan kaki pada sudut 135° lebih cepat daripada yang lain kerana koridor bersudut 135° adalah koridor yang hampir lurus dan memerlukan pergerakan membelok yang kurang dari pejalan kaki dalam koridor bersudut yang lain. Secara perbandingan, 1 kepada 1, 15 kepada 15, dan 30 kepada 30 mensimulasikan keadaan waktu tenang, biasa, dan waktu puncak di koridor bersudut. Ketiga-tiga keadaan ini berkaitan dengan empat faktor yang mempengaruhi halaju pejalan kaki: pembentukan lorong, ketersediaan ruang, gangguan lorong, dan penghindaran perlanggaran. Memperhalusi dua objektif utama, kecepatan pejalan kaki dianalisis berkaitan dengan kepadatan dan kesan pergerakan membelok. Analisis ini dilakukan untuk jarak 2 meter sebelum dan selepas putaran. Jarak 2-meter dari belokan ini adalah jarak toleransi bagi pejalan kaki untuk bertindak terhadap perubahan yang hadir dalam laluan mereka berjalan. Analisis selanjutnya menunjukkan bahawa ketumpatan berbanding terbalik dengan halaju pejalan kaki. Sementara itu, sudut bukaan koridor berkadar langsung dengan halaju pejalan kaki. Oleh itu, bukaan sudut yang lebih besar mengurangkan pergerakan membelok pejalan kaki dan meningkatkan halaju pejalan kaki. Penemuan kajian ini diharapkan dapat menjadi asas yang penting untuk menentukan dan merancang kemudahan pejalan kaki pada masa hadapan, yang merangkumi koridor dengan sudut dan bentuk yang berbeza-beza.

ANALYSIS OF WALKING VELOCITY OF PEDESTRIAN WALKING THROUGH ANGLED-CORRIDOR BASED ON SPATIAL TRAJECTORIES – A BIDIRECTIONAL SCENARIO

ABSTRACT

Corridors can be described as long passages used for ingress and egress routes in between buildings. Meanwhile, angled-corridors are now widely being implemented to design public facilities' ingress and egress routes. Angled-corridors are the walkway between buildings or inside a building containing an angle or bend between the corridor ends. Typically, pedestrians tend to slow down their motion approaching a corner of the corridor. This dissertation is focusing on the effect of angled-corridor on walking pedestrian in the case on bidirectional flow. This study aims to track pedestrian's spatial trajectories while walking through angled-corridor (60°, 90° and 135°) in the case of bidirectional flow,and further to analyse their walking velocity. In achieving the objectives, the experiment the experiment of walking through angled-corridor was conducted at Dewan Serbaguna, Engineering Campus, Universiti Sains Malaysia, for two consecutive days. Three angled-corridors (60°, 90°, and 135°) were set up and three pedestrians distributions, 1-1, 15-15 and 30-30 were used to create bidirectional flow. During the experiment, participants were asked to walk freely in the angled-corridors. A GoPro camera was used to record the trajectories of the pedestrians, which were used for the tracking and analysis purpose. As a result, pedestrians' spatial trajectories were observed and found that in terms of different angled-corridor, pedestrians in 135° walk faster than the other as the angled-corridor is an almost straight corridor and requires less turning movement from the pedestrians. Comparatively, 1 to 1, 15 to 15, and 30 to 30 simulate the conditions of relaxed, normal, and peak hours in the angled-corridors. These three conditions are related to four factors affecting the velocity of the pedestrians: lane formation, space availability, lane interference, and collision avoidance. Further from the two main objectives, the velocity of pedestrians was analysed in relation to density and turning movement effect. This analysis was conducted for the range of 2-meter before and after the turning. This 2-meter distance from the turning is the tolerance distance for the pedestrians to act towards the incoming changes in the walking route. This further analysis identified that density is inversely proportional to the velocity of the pedestrians. Meanwhile, the angle opening of the corridor is directly proportional to the velocity of the pedestrians. Therefore, a bigger angle opening reduces the turning movement of the pedestrians and enhances the velocity of pedestrians. The findings of this study are expected to be a valuable fundamental for determining and designing future pedestrian facilities that include corridors with varying angles and shapes. In the future, this research should be advanced by considering various scenarios associated with turning movement at different angled-corridors.

CHAPTER 1

INTRODUCTION

1.1 Background

Corridors can be described as long passages used for ingress and egress routes in between buildings. Nowadays, we can say that the architectural design has already been enhanced to a new stage where the corridors provided in the design come into certain angles. Thus, angled-corridors are now widely implemented to design the ingress and egress route of the public facilities. Hypothetically, pedestrians tend to slow down their motion when approaching a corner of the corridor.

Kirik et al. (2018) described that based on their discrete-continuous pedestrian model, which focused on 90° angled-corridor and pedestrians' free movement, flow rate and density after the turn are less than before. They justified that speed is higher after the turn. It further explains that congestion is unavoidable before turning, and the density depending on the flow is changed because an internal angle is changed. Those who moved the outer perimeter faster were blocked. Congestion is unavoidable and depends on density before both turns. Therefore, understanding pedestrians' characteristics towards any shape or angle of the corridor are essential to determine the corridor efficiency as an ingress and egress route for pedestrians.

Angled-corridors are the walkway between buildings or inside a building containing an angle or bend between the corridor ends. Commonly, the 90° angle corridor or L-shaped corridor commonly found and easily described by many because of the well-known geometry. Therefore, it can be considered as the most constructed angled-corridor. Additionally, Dias & Lovreglio (2018) and Rahman et al. (2019) had conducted experiments for pedestrians passing through 90° angled-corridors. Besides, some L-shape corridor is slightly angled because that is the only space available or left by the building in between, as shown in Figure 1.1, and it is considered an obtuse angled-corridor.

Figure 1.1: Between 90° to 180° angled-corridor found in between buildings at LRT Taman Melawati Station

The ingress and egress route's turning angle is one of the critical features that must be appropriately designed. Angled ingress and egress routes corridors are popular in public transit, parks, and other public gathering places like universities and colleges. As a response, proper considerations should be taken during the evacuation area's planning and design stages (Dias et al. 2012)

Malaysia has a well-established building code known as the Uniform Building by Law, or UBBL 1984. Local authorities implement and apply to all types of buildings built in the locality. According to UBBL 1984, part III – space, light, and ventilation, any veranda-way or uncovered width should not be less than 2.25 m. Still, in cases involving piers or columns, the veranda-way or footway allowed to be constructed should have a maximum depth of 600 mm from the building's boundary.

The investigation of the pedestrians' trajectories when passing through angled-corridors can be considered limited and require more research. Yue et al. (2021) mentioned that currently, most of the studies on pedestrian evacuation in walking facilities with spatial barriers focus mainly on the effects of shape, position, layout, and type of obstacles on the efficiency of movement and path choice, as well as on the role and mechanism of obstacles. The presence of an angled-corridor in a walkway can be considered an obstacle since obstacles are something that has an impact on the efficiency of the movement or path.

Bidirectional flow means the pedestrians are walking in two directions discording each other. The study of pedestrians walking in bidirectional can be considered as rare as compared to unidirectional flow. Rahman et al. (2017), through the study of empirical investigation of trajectories and desired walking velocity of pedestrians walking through angled-corridor, managed to obtain average velocity and pedestrians' trajectories for unidirectional flow of pedestrians. Ye (2019) justified that a bidirectional stream is not a simple combination of several unidirectional lanes.

The study of pedestrian trajectories towards a different type of angled-corridors for a bidirectional flow should be further studied because there is no empirical relation between pedestrians' density and velocity walking in bidirectional angled-corridors have been determined. Besides, pedestrians' interactions upon meeting at the midway to avoid collisions in the corridors are critical to be observed for future crowd evacuation strategies in bidirectional corridors.

1.2 Problem Statement

This dissertation examines pedestrian walking velocity for an angled-corridor based on spatial trajectories for a bidirectional scenario. Nowadays, corridors' design and layout tend to be more complex with the implementation of corridors with angles. For example, in public buildings (such as train stations, shopping malls, colleges, and parks), many complex geometries of walkways can be seen, and one of them is an angled-corridor (Rahman et al., 2019). According to Dias et al. (2014), these angled-corridors could cause pedestrian flow restrictions, clogging, and jamming during rush hour. As a result, particular consideration must be given proper planning and designing the function of ingress and egress routes for various angled-corridors.

Large crowds may arise in public infrastructure due to daily activities, cultural festivals, or sports events. As a result, there is a risk of an accident when evacuating through the angled-corridors, especially in pedestrians' bidirectional flow. In recent decades, a growing number of people have migrated to cities, resulting in a more bidirectional flow of large-scale activities. As a result, pedestrian traffic and safety are becoming increasingly important. Issues related to the counter-flow movement and its effects on pedestrian dynamics have been raised, Zeng et al. (2021) from day to day. As a whole, it is crucial to recognize the importance of thorough planning and design work in improving the safety, efficiency, and comfort level of crowded evacuation in a building.

Experimental studies are important to be conducted to observe the real situation. The unique behavior of humans that can be considered uncertain depending on the situation needs to be classified into their group of conditions to their same characteristics or action influenced by the situation. For example, Zeng et al. (2021) previously conducted a study to classify common human behaviour while walking in the same situation. From the study, it was suggested to conduct experimental work to classify the common uncertain behaviour of humans while walking. The result can later be compared to the study's result that made the common human behaviourism while walking based on simulation work. Thus, experimental work is important to obtain more compherensive outcomes eventhough human behaviour is hard to be experimented.

1.3 Objectives

The objective of this study is as follows:

1. To track pedestrians' trajectories walking through angled-corridors for different angles, i.e., 60°, 90°, and 135°.
2. To analyze pedestrians' walking velocity in bidirectional flow for angled-corridors for different angles, i.e., 60°, 90°, and 135°.

1.4 Scope of the Study

In order to achieve study objectives, the video footage obtained from previous experimental works conducted in Dewan Serbaguna, Engineering Campus, Universiti Sains Malaysia in 2016 was utilized. From the video footage, several procedures were conducted to obtain the pedestrians' trajectories and analyse their walking velocity. Therefore, the trajectories of pedestrians are determined from image sequences obtained for the conversion of video footage taken during the experiment. Meanwhile, the velocity analysis of this study was conducted based on the trajectories data obtained.

For this study, three major sections have been performed. The experiment setup is the first part. The experiment must set up in a well-controlled environment to simulate pedestrian dynamics accurately. Three angled-corridors, 60°, 90°, and 135°, were used in this setup. Meanwhile, pedestrians will be walking in bidirectional flow from both ends of the corridors in a 1 to 1, 15 to 15, and 30 to 30 proportion.

Video data collection is the second part. A GoPro camera was used for this part. During the experiment, the video camera was mounted on the hall's ceiling rack at a certain height from the floor to cover the entire corner area. Then it recorded the pedestrians' movement. Video data analysis was the final part. This video data analysis was performed in three stages which are:

a) Manually pedestrians' trajectories tracked using Adobe After Effect software.
b) Spatial 2D trajectory data transferred from Adobe After Effect software to Microsoft Excel.
c) Determination of average walking velocity of pedestrians using 2D vector velocity definition.

1.5 Significant of Study

The results obtained from this research are expected to be fundamental data for understanding crowd behavior for future crowd management. Specifically, it contributes to a thorough understanding of the pedestrians' walking behavior while walking through angled-corridors specifically for bidirectional flow. Hence, the findings of this study can contribute to future better corridor design considerations of evacuation strategies concerning emergency response plans.

1.6 Dissertation Outline

In this dissertation, Chapter 1 explained a brief introduction and overview of the study, including the background, problem statement, objectives, the study scope, and significance. The literature review discusses the gap in previous studies and current studies before this topic is explained in Chapter 2. Meanwhile, Chapter 3 mainly describes data extraction and the methodology deployed to achieve study objectives. Chapter 4 discussed the findings. Finally, Chapter 5 highlighted the conclusion and recommendations.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the previous research regarding the fundamental of angled-corridors and bidirectional flow are reviewed, including the pedestrians' trajectories and velocity. The review was mainly focusing on the fundamental, angled-corridors and bidirectional flow of the previous studies. Additionally, interaction among the walking pedestrians is also highlighted in this chapter. Finally, the gap between previous studies is identified.

Shi et al. (2015) mentioned that many studies focused on understanding pedestrian crowd dynamics through theoretical or empirical approaches in past decades. This statement indicates that there is more space to be discovered to justify all the theoretical and empirical approaches results and discussions through the outcomes from experimental works. Human behaviour is unique to be simulated or experimented with because of their uncertain behaviour that depends on the situation that they are facing. However, Rahman et al. (2019) experimented with a control experiment conducted on pedestrians' walking trajectories in unidirectional pedestrians in angled-corridors to justify pedestrians’ walking trajectories and velocity. Thus, experimental works are important to justify all the theoretical and empirical approaches that exist.

An angled-corridor can be described as a long and narrow passage between buildings structured into certain angles between its ends. It is commonly found in the ingress and egress route of pedestrian’s walkways of public facilities such as train stations, malls, parks, and colleges, (Rahman et al., 2019). According to Uniform

Building by Law, UBBL (1984), a 2.25 m width walkway is permissible for construction under certain conditions that will be further discussed in this chapter.

It is found that while walking through angled-corridors or bend corridors, there will be a reduction in pedestrians' walking velocity. Kirik et al. (2018) found flow rate and density after the turn is less than before through an actual experiment. They further justified that speed is higher after the turn. In terms of bidirectional flow, there is a significant difference in the level of service of a bidirectional corridor. Counter-flow negatively impacted the speed of pedestrians, (Gorrini et al., 2016).

2.2 Bidirectional flow

The movement of pedestrians in two directions at the same time is known as bidirectional flow. The basic concept of bidirectional pedestrian flow is that when someone walks from south to north, the other walks from north to south simultaneously and in the same place. Luo et al. (2020) described bidirectional flow as the study of flows that consider two typical pedestrian behavior patterns: following and walking-side preference. It is then further elaborate that pedestrians walking in different directions interact with each other, resulting in self-organization with various spatiotemporal patterns, such as lanes' formation in bidirectional flow and strips in crossflow.

During emergencies such as natural disasters or terrorist attacks, where rapid egress is needed for escape, collective egress played a significant role. One critical feature of collective egress under emergency conditions, according to Shiwakoti et al. (2011), is the turning movement when a sudden change of direction or the layout of the escape area occurs. In order to obtain real-life data, (Shiwakoti et al., 2011) experimented with ants to investigate the effects of turning and a simulation to simulate a crowd of pedestrians at angled escape routes.

According to the simulation results by (Shiwakoti et al., 2011), pedestrians walk through the straight hallway; their collective movement is uniform. Contradictory, when the pedestrians walk through the angled-corridor, congestion was observed at the turning junction, causing a delay in egress, as shown in Figure 2.1. Shiwakoti et al. (2011) concluded that the straight corridor (turning angle of 0°) is the most efficient in terms of flow as compared to other turning angles because the flow rate was reduced in cases of 45°, 60°, and 90° turns as compared to the straight corridor.

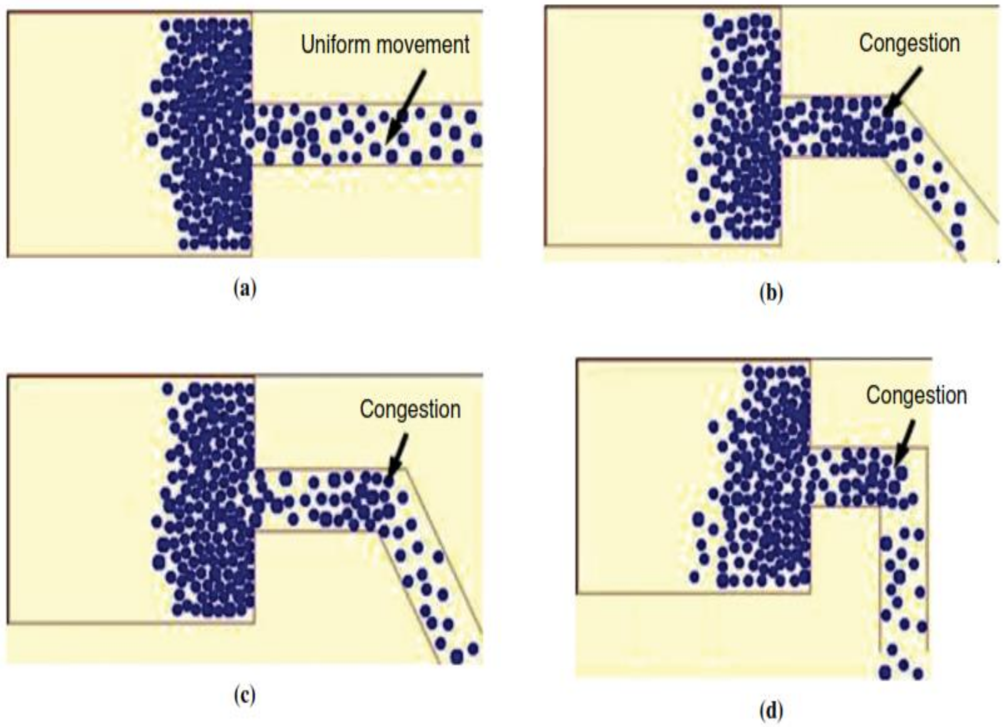

Figure 2.1: Simulation for pedestrians escaping through corridors with different angles

(a) straight (0-degree) corridor, (b) 45-degree corridor, (c) 60-degree corridor, and (d) 90-degree corridor

(Source: Shiwakoti et al., 2011)

2.3 Walking trajectories

All humans have unique behaviorisms that unintentionally serve as markers to differentiate one person from another. This unique behaviourism includes walking trajectories, which are described as an individual's walking pattern as he or she walks from one location to another. Walking trajectories are also subjective, as it can change if the individual is exposed to variables that influence the pattern or walking nature, whether from an external source, an internal source, or a combination of both.

In previous research studies, many experiments have been carried out to examine the dynamics of crowds. An analysis of experimental research on complex pedestrian movement behaviors published by Shi et al. (2015) mentioned that pedestrian movement patterns could significantly affect crowd flow operational characteristics. Therefore, a detailed understanding of those patterns is critical. The study also highlights that complex pedestrian movement behaviors were classified based on movement dimension and pedestrian flow direction. Hypothetically, understanding walking trajectories in every kind of walking corridor are crucial to analyse the impact of the constructed corridors on human walking nature.

2.3.1 Walking trajectories passing through angled-corridors

Observing walking trajectories is crucial, especially at the bottleneck of the corridor, to ensure the pedestrians can pass through the angled-corridors without any collision or other jamming situation. However, generally, it is difficult to obtain any findings or scientific evidence by conducting experiments with humans due to ethical and safety issues. These issues have made analysis of pedestrians' trajectories extremely difficult and challenging, especially in complex situations such as in angled-corridors.

However, several previous research shows that when humans and ants are fleeing in fear, their mutual behavior may be identical. According to Nishinari et al. (2006), ants follow the ants in front of them through pheromone traces, and pedestrians try to follow others during an evacuation to exit safely and efficiently. As a result, ants trajectories data are relevant to substitute human walking trajectories. Dias et al. (2012) found that a right-angled egress path is 20% less efficient than a straight path of the same dimension based on empirical evidence with ants' trajectories experiment results. As a result, right-angled egress paths result in a lower flow rate and a longer escape time when opposed to straight egress paths.

Despite all of the model studies, some controlled experiments were carried out to simulate pedestrian trajectories when walking along angled-corridors. Rahman et al. (2019) conducted controlled experiments to model pedestrian behavior when walking through angled-corridors in unidirectional flow. The study observed that single pedestrians tend to walk in the middle of the path, and the pathway becomes increasingly crowded as the number of pedestrians rises.

2.3.2 Walking trajectories in bidirectional flow

Walking trajectories in bidirectional flow, such as opposing, merging, diverging, weaving, and intersecting, are more challenging to investigate. Opposing flow is a common form of bidirectional flow seen in pedestrian traffic. A pedestrian will switch their preferred walking path in a narrow corridor to avoid colliding with other pedestrians. Meanwhile, merging is a form of joining behavior in angled corridors or pathways and can be described as a combination of turning and weaving. Two walking streamlines interacted with an angle ranging from 0° to 180° is merging behaviors, while diverging can be considered the inverse of merging, where a single flow splits into several flows.

Stability is the important key that differentiates merging and diverging flow. Meanwhile, conflict-avoidance behaviour, like opposing flow, weaving, and intersecting flow, can be considered as the differences. Due to space and time constraints, pedestrians with different walking paths may have to weave or intersect with one another. The interaction angle of the walking path in the weaving flow is a shape angle ranging from 0° to 90°. Such an interaction angle in intersecting flows is an obtuse angle between 90° and 180° (Shi et al., 2015).

Lian et al. (2017) mentioned that pedestrian crowds had been observed to exhibit various self-organized behavior patterns. The phenomenon of lane forming, similar to strip formation at a crossing, originated from pedestrians' tendency to minimize conflicts with oncoming pedestrians in a bi-directional flow. Since two competing pedestrian flows could not push through a bottleneck simultaneously, nonlinear flow formed. Other self-organized behaviors, such as Mexican waves in an ecstatic stadium and stop-and-go waves in a crowded area, showed that pedestrians had nowhere else to go.

2.4 Walking velocity

Pedestrians' walking velocity is an essential factor for both safety and the efficiency of the corridors' design. Mathew (2014) justified that pedestrian speed is the average pedestrian walking speed and expressed in units of meters per second. The Federal Highway Administration (FHWA) Manual on Uniform Traffic Control Devices for Streets and Highways specifies a normal walking speed of 4.0 feet per second (1.2 meters per second). The Highway Capacity Manual 2000 specifies that pedestrian walking speed is determined by the proportion of elderly pedestrians (65 years and older) in the walking population. For walkway calculations, a walking speed of 1.2 m/s is recommended if 0 to 20% of pedestrians are elderly. Adult pedestrians can walk at a speed of 1.2 m/s, according to both the FHWA manual and the Highway Capacity Manual 2000. (Adenan, 2017)

Zhang & Seyfried (2014) conducted an experiment to study the bottleneck effect in pedestrian's walking velocity. Figure 2.2 and Figure 2.3 show the result of their studies consisting of the two built-corridors (short-narrowing and long-narrowing corridors) to justify the restriction on the bottleneck that impacts pedestrians' walking velocity. The duration of its narrowing determines the facility's capability.

A short narrowing has a more negligible restriction effect on pedestrian flow than a long narrowing. In other words, the presence of a corner causes turning behaviour, which decreases the corridor's effective width and creates a bottleneck. Because of the various capacities, no single density-flow relationship can be extended to facilities with various narrowing or geometry types. Since pedestrians' supplies, particularly at congested stations, differ in each scenario, more data is required to assess each facility's capacity, (Zhang & Seyfried, 2014).

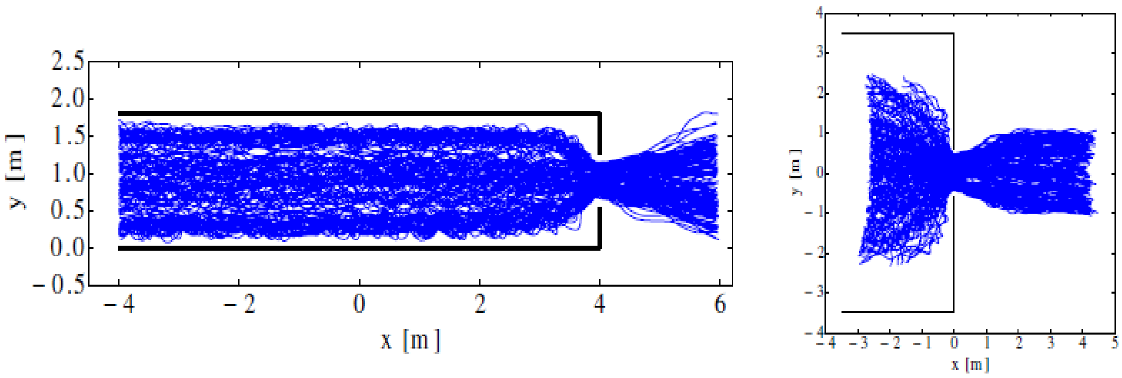

Figure 2.2: Pedestrian trajectories for pedestrians passing a short narrowing

(Source: Zhang & Seyfried, 2014)

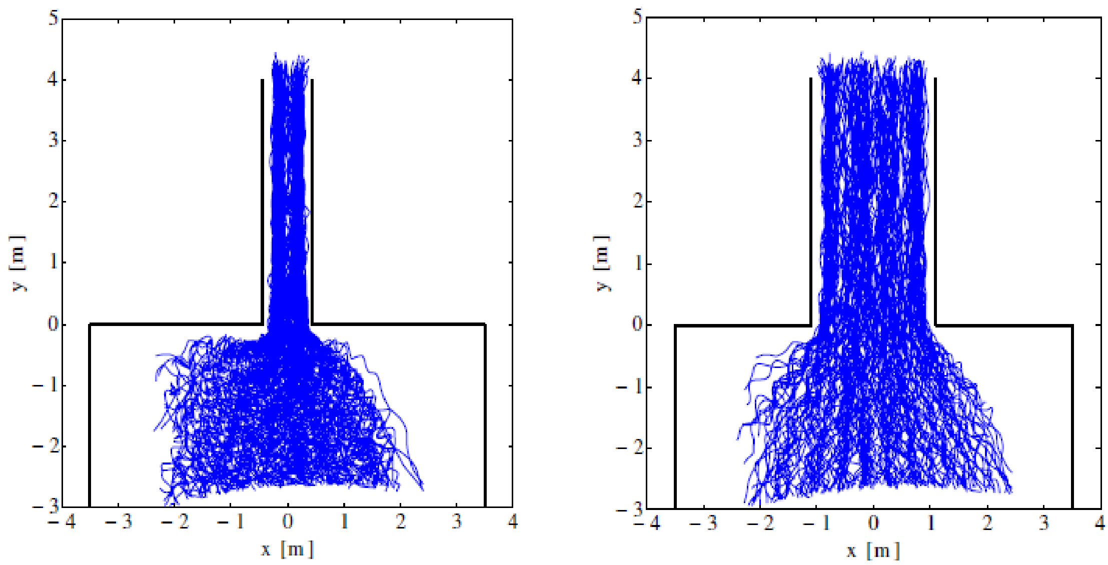

Figure 2.3: Pedestrian trajectories for pedestrians through a long narrowing

(Source: Zhang & Seyfried, 2014)

Therefore, it can be justified that the presence of any changes in pedestrians' walking pathway will give impact to the pedestrians while passing through it. However, the major impact that determines the effectiveness of any built corridor is the velocity of pedestrians passing through the built corridors. Therefore, any restrictions that reduce walking velocity need to be analysed and noted for the future design of the walking corridor.

2.4.1 Walking velocity passing through angled-corridors

Many factors influence an individual's speed, including age, sex, body height, stamina, and mobility impairments. Individuals in groups have a more complicated situation, and their speeds are the product of group interaction (Adenan, 2017). According to the review made by Alias (2019) based on the experiments conducted by Shiwakoti et al. (2011) and Dias et al. (2012) with different angles and densities, it was found that greater angles of rotation have a significant impact on pedestrian outflows, especially in high-density situations.

Yue et al. (2021) described the corridor's presence as an obstacle as a general. Furthermore, they discussed that pedestrians would choose to take the shortest distance when there are no spatial obstacles in the evacuation space and spend the least amount of time evacuating by walking in a straight line. Therefore, the same concept is applied to the pedestrians passing through angled-corridors. Therefore, an angled corner in the middle of the walking pathway is considered a spatial obstacle to pedestrians. Thus, pedestrians may change their evacuation path to the surrounding area, dispersing the entire evacuation area's paths. In other words, pedestrians will avoid and bypass obstacles in the evacuation space that cannot be crossed, passing through them at a slower speed, which will affect path selection and evacuation efficiency in walking facilities.

2.4.2 Walking velocity in bidirectional flow

Shi et al. (2018) mentioned that the name "bidirectional (pedestrian) flow" (sometimes also referred to as counter-flow or opposing-flow) had been given for a phenomenon where groups of people walk in different and opposite directions while interacting with each other. Feliciani & Nishinari (2016) discussed that during the entire process of bidirectional movement, there are five different phases: unidirectional free flow, lane forming, absolute bidirectional flow, lane dissolution, and unidirectional free flow. Pedestrians walk differently on different phases, and the same goes for their velocity. Xue et al. (2020) elaborate that when the movement in both directions is exceptionally high, deadlocks may occur, which is a concept that describes a situation in which people are unable to move and are trapped in their places.

Zeng et al. (2021) used the term entropy, which is widely used in statistical mechanics to describe the uncertainty or disorder in a system and explained that pedestrians' velocity difference is the main factor influencing lane formation. From their experiment, entropy is primarily influenced by the number of pedestrians at the start of movement (roughly before time 20 s); more pedestrians contribute to more significant uncertainty and entropy; then, after time 20 s, entropy decreases due to self-organized activities. After an 80-second transition time, pedestrians choose to follow others to prevent clashes with opposing pedestrians; thus, the system is governed by self-organized activities, and entropy decreases. The density begins to decline towards the end of the experiment, as more pedestrians are walking out of the structure, and no new pedestrian is entering it. Then more available space for pedestrians to walk in the structure, and there is a variety of speeds among pedestrians, resulting in increased entropy. Then, as the number of pedestrians in the system decreases, the speed entropy begins to decrease.

2.5 Interaction between pedestrians

Lanes of people moving in the same direction develop due to collective interactions in which imitation (or following) and collision avoidance (avoiding) play a critical role. Understanding the dynamics of people in a bidirectional flow requires an understanding of lane formation. Pedestrians appear to follow pedestrians walking in the same direction to avoid collisions, contributing to lanes' creation. However, pedestrians attempting to overtake slower pedestrians reduce the lane stability, creating an unpredictable barrier for people walking in the opposite direction. (Xue et al., 2020)

Besides, Alias (2019) justified the presence of repulsive interaction forces among the pedestrians in the corridor that influenced the effectiveness of the built corridor. This repulsive force is divided into two, which are repulsive physical force and repulsive psychological force. The repulsive physical force makes the pedestrians interact with the walls or dead load available in the space. Meanwhile, the repulsive psychological force can be described as the force that made the pedestrians interact with other pedestrians in the space.

Pedestrians move freely under less crowded crowds due to repulsion effects; otherwise, their movement and motion would be affected by repulsive effects with other people (repulsive psychological force), resulting in self-organization phenomena. Repulsive physical effects disrupted the flow of motion when the crowd density increased to where pedestrians collided, (Alias, 2019).

2.6 Summary

Based on the previous study, many experiments, models, and mathematical approaches had been conducted to understand human behaviour while walking, whether through an angled-corridor or not. It was subjective, but the complexity can still be categorized into a specific group of behaviours to analyse the walking patterns and their reflection towards obstacles between the walking routes. Many conditions can be applied when considering some obstacles to the walking corridor such as the angled shape. The terms obstacle used to describe the angle in the corridor because it was justified to be the reason pedestrians need to shift out of the walking comfort.

The review focused on pedestrians' walking trajectories and velocity conducted in two parts: passing through the angled-corridor and in a bidirectional flow. Currently, a limited study has been conducted to study the pedestrian's trajectories and velocity related to angled-corridors and bidirectional flow at the same point. As this condition is occurring in public, it is relevant to further study regarding this relationship.

An experiment-based analysis is particularly important for determining pedestrian walking trajectories and velocity. We may obtain pedestrian walking trajectories based on real-life situations using this method. Average pedestrian velocity can be calculated using spatial data from trajectories. According to the literature, there are few studies of pedestrian behaviour that are focused on experimental study. However, the previous study's data is vital as a baseline and improved in this study.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter presents the provisional topic study, tracking of spatial walking trajectories, and the analyses performed, which are presented in three main phases. Each section contains an in-depth description of the procedure employed in achieving the objectives of this study.

This research study utilised previous experiments' video footage as the metadata to observe and analyse into deeper the study field. Additionally, Autodesk® MAYA® 2016 (MAYA) software and Human Behaviour Simulator (HBS) tool were employed to determine the pedestrians' spatial walking trajectories. Figure 3.1 describes the framework of the research study to achieve the research objectives.

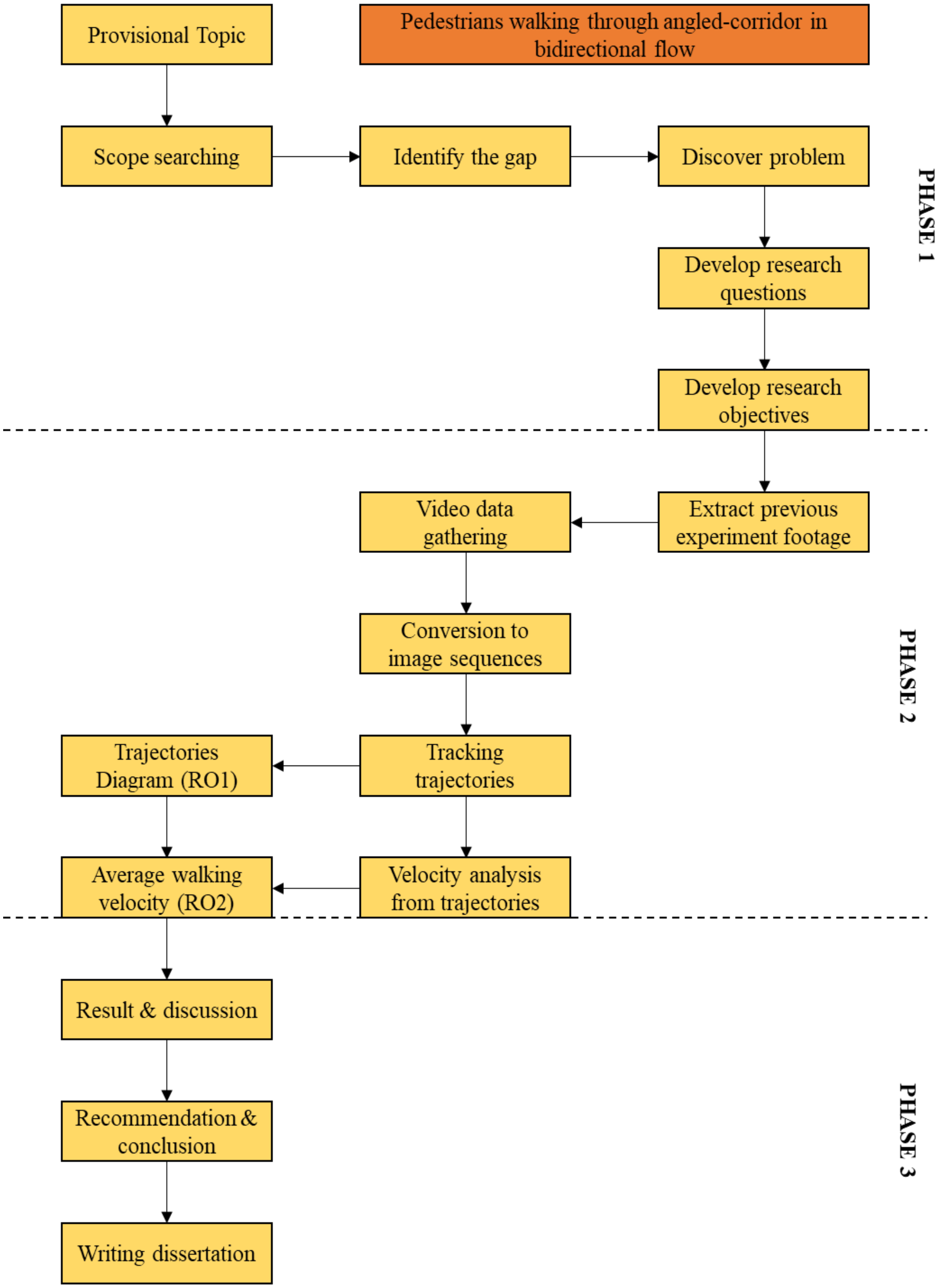

Figure 3.1: Research study framework

3.2 Background of the Experimental Work

The experimental work took place on 5th and 6th November 2016 at Dewan Serbaguna, Engineering Campus, Universiti Sains Malaysia. The pedestrians were recruited from the students of Engineering Campus, Universiti Sains Malaysia. Altogether there were 120 male and female subjects involved as the pedestrians. The pedestrian's distribution based on gender for that two days is depicted in Table 3.1.

Table 3.1: Pedestrians distribution based on gender during the experiment

Date/ Pedestrians	Male	Female	Total
5th November 2016	20	40	60
6th November 2016	26	34	60

Three angled-corridors were considered in experimental work, i.e., 60°, 90°, and 135°. These angles represent acute, L-shaped, and obtuse angled-corridors, respectively. These three angles were chosen due to commonly found in public facilities. During the experiment, pedestrians were asked to walk, and the activities of walking through angled-corridors were captured via video camera. The video footage collected during the experiment was used to determine the trajectories. Additionally, to replicate actual walking activities, the pedestrians have not been informed about what kind of obstacles or angles are coming up in front of them; they are just being instructed to walk in their normal walking condition.

3.2.1 Experimental Setup

Following the specifications, three different degrees of angled-corridor facilities were built. Figure 3.2, Figure 3.3, and Figure 3.4 show the built configuration of three angled-corridors, 60°, 90°, and 135°, respectively. Note that the width of the corridors' setup was set to be 2.25 m to comply with the Uniform Building by Law, UBBL 1984. The corridor's length was set at 7 m.

The participant's walking action defines the task for the bidirectional flow. A white shirt and a blue or red cap have been provided to the participant. They were asked to stay at the end of the corner in waiting rooms before starting the experiment. This experiment's inflow rates were consistent for all experiments with a different number of pedestrians (N = 1, 15, 30, 45, and 60).

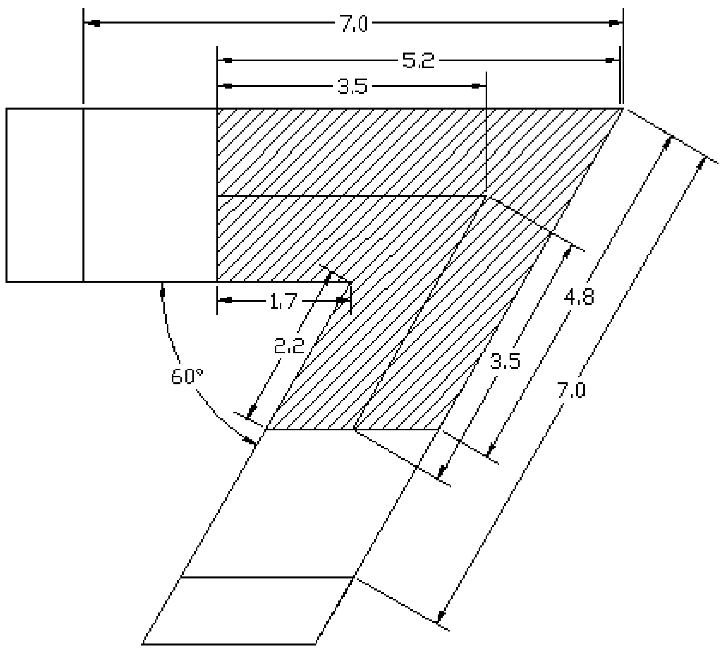

Figure 3.2: Layout of 60° Corridor (Unit is in Meters)

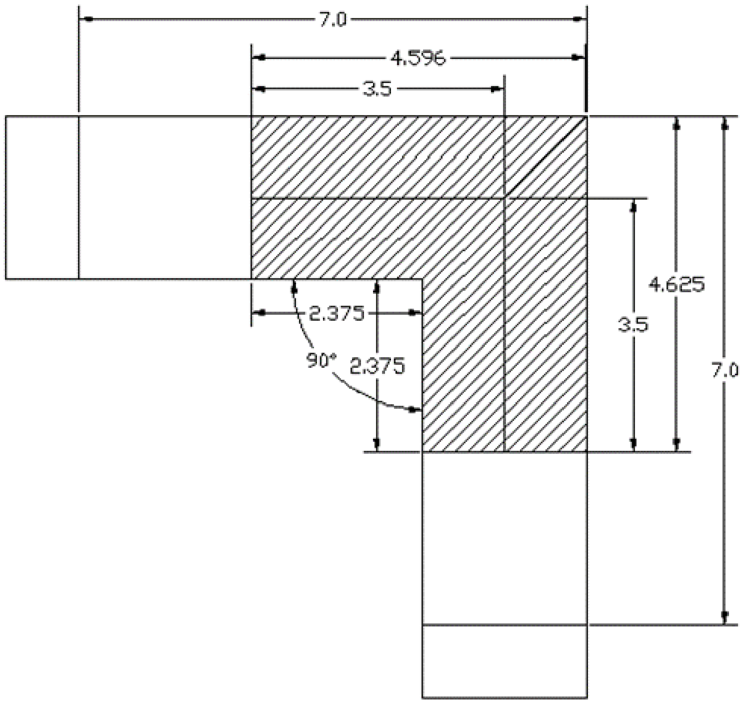

Figure 3.3: Layout of 60° Corridor (Unit is in Meters)

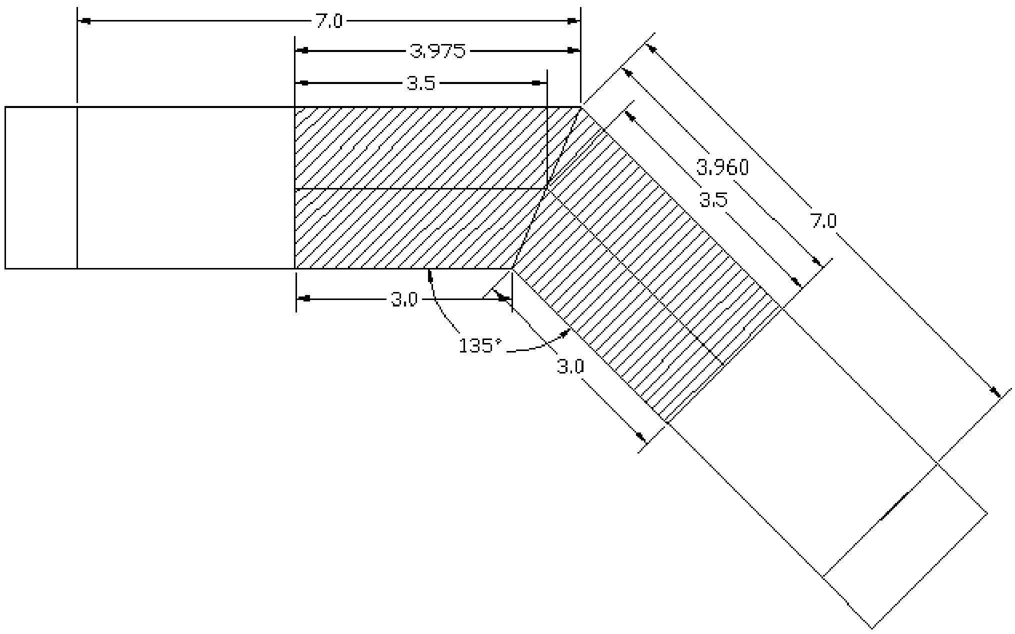

Figure 3.4: Layout of 60° Corridor (Unit is in Meters)

Before the participants were asked to perform walking tasks, pedestrians have been grouped accordingly and stand at both ends to create the bidirectional scenario.