EXPERIMENTAL INVESTIGATION OF PEDESTRIAN FLOW THROUGH A CORRIDOR WITH CORNER

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ABSTRAK

Kelajuan pejalan kaki dipengaruhi oleh banyak faktor seperti ketumpatan pejalan kaki, kemudahan koridor dan sebagainya. Oleh kerana kelajuan pejalan kaki mempunyai pelbagai keperluan dan kebolehan, beberapa pendekatan untuk menentukan dinamik pejalan kaki telah dilakukan. Federal Highway Administration (FHWA) Manual on Uniform Traffic Control Devices for Streets and Highways dan Highway Capacity Manual 2000 menetapkan bahawa kelajuan untuk pejalan kaki adalah 1.2 m/s dengan sifar pejalan kaki warga tua yang terlibat. Pelbagai kajian telah dilakukan untuk mengkaji dinamik pejalan kaki termasuk pemodelan dan simulasi. Walau bagaimanapun, setakat ini tidak banyak perhatian diberikan untuk mengkaji dinamik pejalan kaki dari segi pengukuran empirikal. Selain itu, kajian tentang had laju pejalan kaki di koridor yang bersudut adalah agak jarang. Oleh itu, kajian ini dijalankan berdasarkan dua objektif utama iaitu untuk menentukan kelajuan pejalan kaki secara empirikal bagi aliran bebas satu arah di koridor yang bersudut dan juga untuk menentukan kelajuan pejalan kaki dari segi jantina. Dalam kajian ini, kita mengkaji perkembangan terkini dalam dinamik pejalan kaki yang berlaku dalam pelaksanaan eksperimen di bawah keadaan makmal dengan penglibatan 60 pejalan kaki dan pengekstrakan trajektori melalui analisis video yang dilakukan pada kemudahan koridor yang bersudut, iaitu sudut 60°, sudut 90° dan sudut 135°. Koridor yang lurus dengan sudut 180° digunakan sebagai rujukan asas dalam eksperimen ini. Data akan dianalisis untuk setiap pecahan kerja yang diberikan di mana lebar koridor dan jumlah pejalan kaki yang berbeza digunakan bagi setiap sudut. Mengejutkan, hasil dapatan menunjukkan bahawa purata kelajuan pejalan kaki bagi lelaki adalah lebih rendah daripada purata kelajuan pejalan kaki perempuan dan digunakan pada hampir kesemua

pecahan kerja. Diantara tiga sudut yang digunakan, kemudahan koridor dengan sudut 135° menunjukkan purata kelajuan pejalan kaki berjalan adalah malar walaupun bilangan pejalan kaki meningkat. Untuk menentukan objektif kedua dalam kajian ini, graf kekerapan kumulatif dilukis untuk menentukan persentil peratusan kelajuan pejalan kaki ke-15 dan ke-50 bagi kedua-dua jantina iaitu perempuan dan lelaki merujuk kepada parameter yang terlibat. Dapatan daripada kajian ini adalah penting terutama bagi mereka bentuk struktur terutama koridor pejalan kaki selain bermanfaat untuk merangka pelan tindakan kecemasan.

ABSTRACT

Walking speed of pedestrians is governed by many influencing factors such as density of pedestrian, corridor facilities and so on. Since pedestrian have wide range of needs and abilities, several approaches for determining pedestrian dynamics have been done. Federal Highway Administration (FHWA) Manual on Uniform Traffic Control Devices for Streets and Highways and Highway Capacity Manual 2000 includes a walking speed of 1.2 m/s with zero elderly pedestrian involved. Many research studies have been done in investigating the pedestrian dynamics which includes modelling and simulating. However, so far not much attention has been paid to their qualitative measurements. Besides, the study of pedestrian walking speed on corridor with corner is relatively rare. Therefore, this study is carried out under two main objectives which are to determine empirically walking speed of pedestrian for unidirectional free flows at corridor with corner and also to quantify the walking speed of pedestrian by gender. In this paper, we review the recent developments in pedestrian dynamics, by the implementation of experiments under laboratory conditions with up to 60 pedestrians and extraction of trajectories by video analysis in complex facilities of corridor with corner, e.g. 60° corner, 90° corner and 135° corner. A straight corridor with 180° is used as a baseline in this experiment. The data is analysed for each task given in which different number of pedestrians and width of corridor are used for each corner. Surprisingly, the result shows that average walking speed of male is lower than average walking speed of female and applied at almost all tasks. Within three different corners, 135° corner facility shows a constant average walking speed of pedestrian even though the numbers of pedestrians are increased. To quantify the second objective in this study, the cumulative frequency graph of corridor walkway was plotted to determine

15th percentile and 50th percentile of walking speed both for female and male pedestrians relative to parameters involved. The results are of particular importance for designing the structure especially at walking corridor and also beneficial for the design of an emergency response plan.

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CHAPTER 1

INTRODUCTION

1.1 Background

A corner facility or an L-shaped geometry is a common geometrical condition that frequently can be found in all kinds of buildings. For instance, a corner of the emergency staircase which is usually located at building edges (end of the building), and the L-shaped of the corridor. Logically, we can assume that there will be changes to the human walking velocity, like slow down effect, when approaching and walking pass the corner. This situation subsequently will trigger restrictions to pedestrians flow. Thorough understanding of pedestrian flow for any geometrical shapes in a specific building is crucial since it is a basis in designing effective pedestrians' facilities and emergency response plan.

Study on the effect of a corner with different angle is rare and need more research. A research by Oh et al (2014) validate the evacuation dynamics with various exit angles in bottleneck by comparing between simulation using Discrete Element Method with psychological effect and experiment by using mice. The results show a fairly good agreement in qualitative view in spite of some differences in the quantification view. Straight corridor walkway is more effective in both for transportation and safety issues. As improving design by architectural perspective, lots of unique geometry of walkway is introduced and this lead to another concern of how walking speed of pedestrian may give an impact to the effectiveness and efficiency of walkway corridor. Wong et al (2010) formulated the model of pedestrian bidirectional based on Drake's model and calibrate it using a controlled experiment of bidirectional pedestrian stream. All parameters such as speed, density and flow were determined for this research. As a results, the crossing capacity decreases when the intersecting angle increases, with the head on bidirectional situation being the worst case scenario.

This study is focused on determining the walking speed of pedestrian for unidirectional free flows at corridor facility under two main variables which are width and angles of corridor. An experiment are conducted which involved a maximum 60 pedestrians which is students of Universiti Sains Malaysia in which pedestrians were asked to walk in free movement of unidirectional flow on designated walkways with different levels of width and angles of corner. The movements of pedestrians were video recorded and the macroscopic quantity of speed was then calculated. Besides, this study also provides two parameters that are commonly used in traffic engineering and traffic safety which is 15^{th} and 50^{th} percentiles walking speed of pedestrian for every tasks given. As references, Federal Highway Administration (FHWA) Manual on Uniform Traffic Control Devices for Streets and Highways and Highway Capacity Manual 2000 are used in this research.

1.2 Problem Statement

Corner corridor is one of the geometrical or facilities that could trigger restrictions to pedestrians flow and jam during rush hour. There are numerous reasons that lead to jamming at corner facilities such as width of corridor, density of pedestrian, structure of the building, psychological effect and so on. In this study, the focus is to determine the walking speed of pedestrian under two variables which are angles and widths of corner facility. Many recent studies focused on straight corridor and bottleneck effects on pedestrians flow and dynamics. However, study on the effect of walking speed at corner with different angle is comparatively rare. It is believed that corner facility effects should be further studied to improve quality and effectiveness of the design of walking facility.

Besides, the study area for this research is at School of Civil Engineering, Engineering Campus Universiti Sains Malaysia in which the width that has been designed for footway is 1.5 meters. Based on Uniform Building by Laws 1984, the specification for width of footway that must be followed for every building is 2.25 meters. The case might be happened due to low number of pedestrians that use the footway thus probability of jamming to occur is low and almost zero. But then, the reason is still unclear and extra study is needed.

1.3 Objectives

i. To determine empirically the walking speed of pedestrian for unidirectional free flows at corridor facility by considering different widths and angles of corridor;
ii. To quantify the walking speed of pedestrian by gender at corner corridor.

1.4 Scope of Work

For this study, experimental based analysis is used to determine the walking speed of pedestrians. There are three main parts that need to complete for this study. First part is experiment setup. Experiment needs to be setup under well controlled environment so that it will be able to reproduce pedestrian dynamics in realistic way. There are about 51 tasks for the whole experiment and each task has different levels of widths and angles of corridor designated for pedestrians to walk.

The second part is video data gathering. For this part, a GoPro camera is used. The video camera is mounted on the rack of the ceiling of the hall at certain height from the floor to cover the whole region of the corner during the run of experiment to record the movement of pedestrians. The last part is video data analysis. Video analysis is performed in three stages: (i) conversion from video image to images sequence; (ii) track of pedestrians' trajectories; (iii) determination of walking speed of pedestrians. Three parameters obtained from this study are average walking speeds, 15th percentile walking speed and 50th percentile walking speed. Cumulative frequency graph is plotted to obtain 15th and 50th percentile walking speed of pedestrians.

1.5 Significance of Study

1. The results from this research are expected to be useful database and tools for designing and dimensioning of future pedestrian facilities which involves corner shaped geometries in all kinds of building thus contributing to better emergency response plan;
2. Precise quantitative empirical data from this research can be fundamental data for understanding crowd behaviour for future crowd management studies.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The understanding of pedestrian flow and evacuation behaviour in a building is useful due to immediate applications in a building design, pedestrian facilities design, safety assessment and management of emergency walkway. In recent decade, increasing numbers of complex types of facilities in a building have become one of the favourite geometries in architecture for building aesthetic. For instance, stairs, crossings, T-junctions, corners, etc. With such facilities, the dynamics of pedestrians' stream will be more complex and no wonder the uncertain behaviour and non –adaptive behaviour of pedestrians may emerge during an emergency situation. In these issues, the central problems in pedestrian dynamics need to be addressed. A large number of models have been developed in the past to analyse and anticipate crowd behaviour in different context. Most of them are able to reproduce crowd phenomena qualitatively. Before using a model to predict quantitative results like total 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 an overview of pedestrian dynamics and several literatures on investigating pedestrian dynamic both by experiment and modelling. All the input from past studies is very crucial as references in this study.

2.2 Pedestrian Walking Behaviour

Movement of pedestrians is a fundamental part of a multi-mode and multi-level public transportation system. In contrast to vehicular movements, pedestrians interact continuously with each other and their surrounding infrastructure/environment, changing their walking direction and speed frequently. In particular, when large numbers of people gather at a shared location, the movements of the pedestrian crowd become increasingly unpredictable due to complex crowd behaviours (e.g., crossing, turning, merging behaviours etc.) driven by interpersonal interactions. Thus, it is crucial for traffic planners and managers to understand the complex movement behaviours of pedestrian crowds for both efficiency and safety purposes.

Many research studies have been carried out an experiment to investigate the crowd characteristics. Xiaomeng Shi et al., (2015) have done a review of experimental studies on complex pedestrian movement behaviours. Given that pedestrian movement behaviours may have a significant impact on the operational features of crowd flows, it is imperative to have a thorough understanding of those behavioural characteristics. The study also stress that complex pedestrian movement behaviours were classified based on the movement dimension and direction of pedestrian flows.

As stated in aforementioned studies, uni-directional flow refers to movement behaviour with only a united stream of flow in a particular direction. Movement behaviour such as straight walking, overtaking and turning can be put into this category. Overtaking and turning behaviours of pedestrian are more complex compared to straight walking. The action of overtaking in reality as such pedestrians with a higher walking speed are likely to overtake those with a lower speed so as to preserve their desired walking speed. Overtaking behaviour usually occurs in a united walking streamline when a temporary change in direction is needed by the participants who walked with a higher walking speed. Besides overtaking, pedestrian also tend to make turning movements. This turning movement can be frequently observed during a pedestrian's walking process when there is a need for directional change in walking streamline. Although a change of direction is necessary for every participant in the turning process, pedestrians in turning flows share a united direction in both the before and after turning stages.

In contrast to uni-directional flow, multi-directional flow such as opposing, merging, diverging, weaving and intersecting, are more difficult to investigate. Opposing flow, as a typical kind of bidirectional flow, can be frequently observed in the daily traffic behaviours of pedestrians. In a narrow corridor, a pedestrian has to adjust his/her desired walking path for collision avoidance purposes. As for merging, it is a sort of joining behaviour, which can be regarded as a combination of turning and weaving when occurring in angled corridors or on pathways. In merging behaviours, two walking streamlines interacted with an angle from 0º to 180º, whereas for diverging, it can be regarded as a reverse behaviour of merging, where a united stream diverges into multiple streams. The difference between entering a door and diverging flows lies in the stabilities of these flows. Similar to opposing flow, weaving and intersecting flow can also be regarded as conflict-avoidance behaviours. Pedestrians with different walking directions may have to weave or intersect with each other due to conflicts in space and time. In weaving flow, the interaction angle of pedestrian walking streamlines is a shape angle ranging from 0º to 90º. In intersecting flows, such interaction angle is an obtuse angle ranging from 90º to 180º.

For both uni-directional and multi-directional flow, the directions of walking streamlines in movement behaviours in this category are different. Thus, there is an increase in the number of interactions compared to uni-directional flows. The interaction angle of different walking streamlines is an important factor that drives microscopic interaction behaviours. Thus, we categorize multi-directional movement behaviours according to the number of walking streamline directions and their interaction angles.

In another research by Ning GUO et al., (2012) on walking behaviour of pedestrian groups in the Merchandise Streets, it is stated that almost all the 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 organization 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 two 2-member groups moving together. The two essential properties of the group also affect the aggregated speed, especially for the widely observed 2-member group. Our result is useful to traffic management and safety control, especially for the design of public infrastructure.

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 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 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 crowd evacuation planning.

2.3 Building Walkway Facilities (Corner, T-shaped and straight corridor)

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 come 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 the engineers to take a 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 the users.

Lots of researches 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 setup. 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 the 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. In such a situation, it is questionable whether an urge or a push will lead to a benefit.