SIMULATION OF A COMPOSITE QUEUING MODEL OF THE ENTRANCE AND EXIT OF PILGRIMS FROM AL-MASJID AL-HARAM

by

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ABSTRAK

Matematik sentiasa menyediakan penyelesaian bagi masalah kehidupan yang praktikal. Kajian ini menggunakan matematik untuk mencadangkan penyelesaian bagi masalah kesesakan semasa mengerjalan amalan “Tawaf” haji. Satu daripada ritual / amalan semasa mengerjakan haji adalah “ Tawaf”, iaitu mengeliling Kaabah sebanyak tujuh (7) kali. Amalan ini adalah di antara ‘masalah’ yang dihadapi oleh jemaah haji dalam musim haji apabila jemaah haji sama ada secara individu atau berkumpulan tiba untuk melakukan Tawaf. Semua jemaah yang tiba dibenarkan melakukan Tawaf pada bila-bila masa sahaja. Kesesakan jemaah haji di kawasan Kaabah adalah maksimum pada masa-masa tertentu. Akibatnya, pergerakan jemaah di kawasan Kaabah menjadi terlalu perlahan dan adakalanya terhenti. Tambahan pula, data empirik tentang musim haji adalah berbagai-bagai. Justeru, ia amat mencabar untuk mengkaji sistem yang sebenar. Kajian ini mencadang untuk membina suatu model tentang ketibaan dan pelepasan jemaah haji melalui model barisan rencam simulasi, untuk membina suatu model baru dalam usaha mensistemkan pergerakan keluar dan masuk jemaah haji dari Masjidilharam semasa musim haji. Data bagi model baru yang dicadangkan dalam kajian ini dikumpul daripada video “Tawaf.” Bahasa simulasi yang digunakan dalam kajian ini adalah Arena, yang merupakan bahasa simulasi paling popular. Arena merupakan bahasa simulasi bergrafik bagi simulasi diskret dan selanjar, yang digunakan untuk membina sesuatu model. Berdasarkan keputusan simulasi di lima buah pintu utama Masjidilharam, ditemui bahawa masa-masuk puncak, iaitu daripada kesesakan

tertinggi hingga terendah adalah pada pukul 5 pagi, 12 petang, 11 pagi dan 5 petang. Dengan kata lain, masa-keluar puncak dari Masjidilharam, iaitu daripada kesesakan tertinggi hingga terendah adalah pada pukul 7 pagi, 8 pagi, dan 10 pagi. Kajian ini menyimpulkan bahawa penggunaan simulasi daripada model barisan rencam merupakan suatu langkah yang amat menggalakkan dalam mengkaji kesesakan pejalan kaki.

SIMULATION OF A COMPOSITE QUEUING MODEL OF THE ENTRANCE AND EXIT OF PILGRIMS FROM AL-MASJID AL-HARAM

ABSTRACT

Mathematics has always provided solutions for practical life problems. This study uses mathematics to suggest solutions to the problem of overcrowd during ‘Tawaf’ ritual of Hajj. One of the rituals during Hajj is the ‘Tawaf”, that is the circling seven times around Ka'aba. This ritual is among the ‘problems’ faced by pilgrims in the Hajj season due to the overcrowd occurring when individuals or groups of pilgrims arrive to perform the Tawaf in random order. All arrivals are allowed to perform the Tawaf at anytime. The density of pilgrims circulating close around Ka’aba reaches the maximum at certain times of the day. Consequently, the movement of people in the vicinity of Ka'aba becomes very slow and at times comes to a halt. Furthermore the empirical data concerning the Hajj is manifold. Thus, it is very challenging to study the real system. This study proposed to model the arrival and departure of pilgrims by simulation composite queuing model to build a new model to systemize the entrance and exit of pilgrims from AlMasjid Al-Haram during the Hajj season. The Data of the new model proposed in the current study is collected from video of Tawaf. The video is made into a series of captured shots and thus an image processing of the photos is made. The simulation language used in this study is Arena which is currently one of the most popular simulation languages. Arena is a graphical simulation language for discreet and continuous events simulation which has been used to build a model. From the simulation results of the five main gates of Al-Masjid Al-Haram, it was found that the peak hours of entrance from highest density to lowest were at 5 am, 12 pm, 11 am and 5 pm. On the other hand, the peak hours of exit from Al-Masjid Al-Haram from highest density to lowest were at 7 am, 8 am, and 10 pm. This study concluds that using simulation of a composite queuing model is an encouraging step for studying the pedestrians' congestion in large events.

Chapter 1

Introduction

1.0 Introduction

Crowd can be defined as a group of pedestrians gathered in a place for similar or sometimes different purposes. One of the important large crowd events in the world is Al-Hajj to Mecca (Muslim mosque in Saudi Arabia). Most of the Hajj rituals must be completed within a specific period of time. One of important event done in Al-Masjid Al-Haram when pilgrims go to doing Al-Tawaf.

In this chapter we outline such important points related to this study as the Hajj season, Modeling, Simulation, and Arena Program.

1.1 Background of the Study

1.1.1 Al-Hajj season

Hajj is one of the five pillars (central duties) of Islam. It is a set of acts of worship to be performed in and around Makkah at least once in a lifetime by every muslim satisfying certain conditions (AlGadhi et al. , 2001). One of the rituals during pilgrimage is the ‘Tawaf’, which is circling anticlockwise around the Ka'aba seven times. The nature of today’s Hajj (Islamic pilgrimage) requires substantial planning and effort to provide support and infrastructure (Al-Yafi, 1993). However, Hajj is considered as one of the world's largest crowd movements, because more than two million pilgrims converge every year at the same time to perform their religious duty. Furthermore, pilgrims come to Macca from all over the world to do the same activities at the specific times in a different age, health, gender, socio-economic background, cultures and so on. The duration of Hajj activities commences on the ninth day and terminates on the twelfth day of the twelfth lunar Arabic months. (Al-

Haboubi, 2003). In the last two decades the number of pilgrims increase yearly. As for 2010, about three million pilgrims participate in this annual pilgrimage (Amanullah, 2010). Table 1.1 shows the numbers of pilgrims during the last six years according to the reports submitted from the Central Department of Statistics and Information in the Ministry of Hajj – Saudi Arabia.

Table 1.1: The number of pilgrims during the last six year (Ministry of Hajj,2010)

YEAR	NUMBER OF PILGRIMS
2005	1,534,759
2006	1,654,407
2007	1,707,814
2008	2,408,849
2009	2,313,278
2010	2,789,399

In fact, the human behavior is a complex and there is difficult to build a perfect model of the crowd. Hence, simple models consider pedestrians resembling each other or with unimportant differences (Sarmady, 2008). However, adding more details to available models may help to achieve more realistic simulations. In recent years, more complex models are being used which adopted different parameters such as psychological and social traits of pedestrians, communications between agents, roles of leaders, leading to more realistic simulation results (Cunningham and Cullen, 1993), (Zhang and Baoming, 2011). Thus, researchers had attempted to simulate behaviors specific to dense crowds such as pushing, falling, trampling and stampede. Even though different levels of success had been achieved, more time and work are needed to build models with realistic results, which can at the same time reproduce behaviors of crowds in different situations and scenarios (Sarmady, 2008).

The behavior of pedestrians is different when he or she has knowledge about the place or not, the communication between pedestrians has important impact on this (knowledge transfer), small number of pedestrians, who know the environment, help others to find their way better. In a crowded place, finding the way is relatively easier (people become a "guide" in finding a way out).

In this large event Al-Hajj in Mecca many accidents happened as a result of the stampede through the different rituals of Al-Hajj (Africa, 2007), table 1.2 records of accidents for the past decades.

Table 1.2: Some accidents during the pilgrimage seasons (Africa, 2007)

Date	Accident
July 1990	1426 pilgrims dead, a stampede inside a pedestrian tunnel (Ma'aisim tunnel) leading out from Mecca towards Mina,
May 1994	270 pilgrims dead during the stoning ritual
May 1995	Three pilgrims dead and 99 others injured by a fire in the camp area for the pilgrims in Mina.
April 1998	More than 118 pilgrims dead during a stampede in Mina.
March 2001	35 pilgrims dead, during the stoning ritual
February 2003	14 pilgrims dead, including six women on the first day of the stoning ritual in Mina.
February 2004	251 pilgrims dead and another 244 injured in a stampede during the stoning ritual in Mina
January 2006	346 pilgrims dead and more than 289 pilgrims injured caused by huge fire

Thus, crowd-control techniques have became critical with a big challenge to study the real system due to the large numbers of people and the empirical data concerning the Hajj is manifold (AlGadhi et al., 2001). Nowadays, most of the researchers turn to simulation in order to understand and give the approximate perception of the real system.

1.1.2 The Geometric View of Al-Masjid Al-Haram

The total number of the Al-Ka'aba doors are 176 doors, only 5 doors are considered the main doors, which directly lead to Al-Tawaf area. As it is shown in Figure 1.1, the Ka'aba has five main entrances that pilgrims can enter through. The first entrance is called King Fahad, the second one is King Abdl-Aziz which is considered the main entrance because the majority of the pilgrims enter through it. The third one is the Alsalam, the fourth is the Fatah and the fifth is the Umrah. All the pilgrims must do the Tawaf (Anticlockwise circumambulation) around Ka'aba seven times.

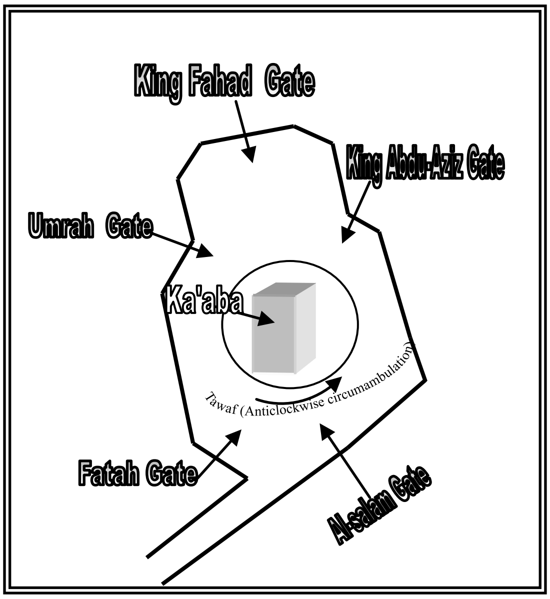

Figure 1.1 Simple diagram of Al-Ka'aba

1.1.3 Statements of Problems Faced by Pilgrims during Al- Tawaf

1. The groups of pilgrims arrive to perform Tawaf in a random order.

2. All arrivals are allowed to perform Tawaf at anytime.

3. The density of pilgrims close to the Ka'aba reaches a maximum at times.

4. The movement of people in the vicinity of the Ka'aba becomes very slow.

5. After completion, the pilgrims move outward in a way that conflict with the main direction of flow.

The general view of the crowded place through Al-Tawaf is presented in Figure 1.2.

Figure 1.2 The crowded place in Al-Tawaf activity

1.2 Models: approximations of real - world events

1.2.1 Ways to Study Real System

There are many possible ways to study any system in the world based on the study carried out by Law and Kelton, 1982, the general ways which can be used to study any system can be summarized in figure 1.3.

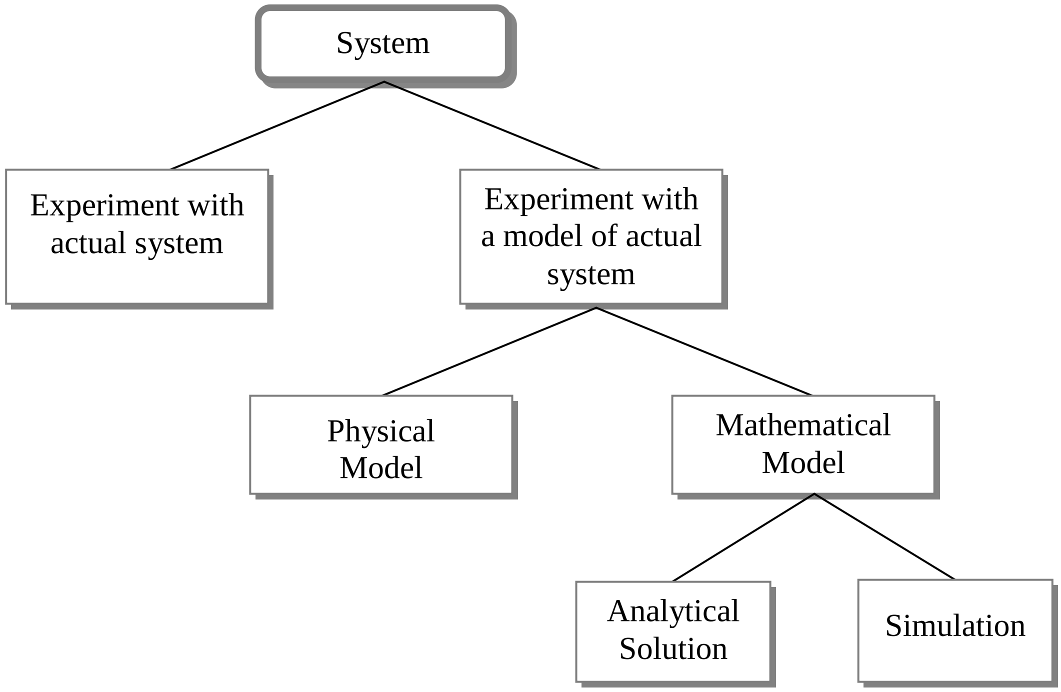

Figure 1.3 Ways to study real system (Law and Kelton, 1982)

According to Figure 1.3, to build a mathematical model, we must create a model approximating an event followed by simulation, which allows for the repeated observation of the model. After one or many simulations of the model, a third step takes place and that is analysis. Analysis helps in drawing conclusions, verifying and validating the research objectives, and making recommendations based on simulations of the model (Sokolowski and Banks, 2009).

1.2.2 Model Definitions

A model is an abstraction or a mathematical representation of a problem of interest and it is an essential part of the process of solving that problem, a mathematical model is an abstract model that uses mathematical language to describe the behavior of a system (Sarker and Newton, 2008). However, it is a representation of the construction and working of some systems of interest. A model is similar to the real system but simpler than it. One purpose of a model is to enable the analyst to predict the effect of changes to the system (Maria, 1997) . Mathematical models can take many forms, including but not limited to dynamical systems, statistical models, differential equations, or game theoretic models. These and other types of models can overlap, with a given model involving a variety of abstract structures (Eykhoff, 1974). Mathematical modeling problems are often classified into black box or white box models, according to how much a priori information is available of the system. A black-box model is a system of which there is no a priori information available. A white-box model (also called glass box or clear box) is a system where all necessary information is available. Practically all systems are somewhere between the black-box and white-box models, so this concept only works as an intuitive guide for approach. Usually it is preferable to use as much a priori information as possible to make the model more accurate (Bender, 1978). Cross and Moscardini (1985) Explained the process of modeling by dividing it into four broad categories of activity, namely building, studying, testing and use. A pictorial representation of potential routes through the stages of modeling is shown in Figure 1.4:

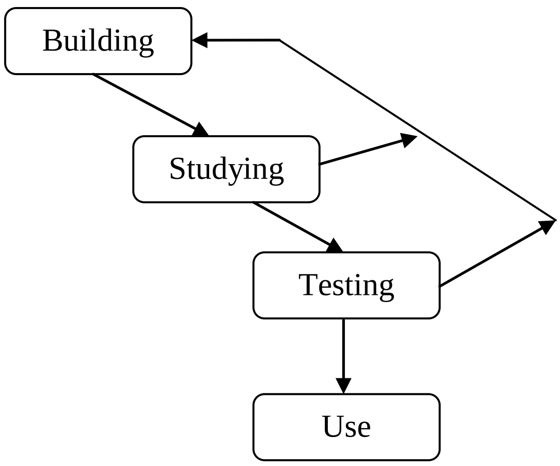

Figure 1.4 The Stages of modeling (Cross and Moscardini, 1985)

The process of repeated iteration is typical of modeling projects, and is one of the most useful aspects of modeling in terms of improving the understanding about how the system works.

1.3 Simulation

Computer simulation modeling has been used since the 1950s and is proven as a successful and useful tool to support the decision making (Tahar, 2006).

Simulation is one of the important problem solving techniques which is used to solve the problems that are difficult to solve analytical methods or numerical methods (Kelton and Sadowski, 1998). Thus, it also refers to the broad collection of methods and applications to mimic the behavior of a real system. In simulation, the computer has been used to evaluate a model numerically over a time period of interest and data are gathered to estimate the desired true characteristics of the model (Law and Kelton, 1982). Actually, simulation is the imitation of the operation of a real-world process or system over time whether it is done by hand or computer (Banks, 2000).

Nowadays, computer simulation is growing in popularity as a methodological approach for researchers (Dooley, 2002). The research methods must make a variety of assumptions about the exact cause and effect nature of the studied system. Simulation also allows researchers to suppose the intrinsic complexity of the systems. If other methods answer the questions “What happened?, and how?, and why?” simulation helps answer the question “What if?” .Simulation enable researcher of more complex systems because it creates observations by “moving forward” into the future, by looking to the backwards across history to inference what happen in the future , and how? (Dooley, 2002). In a summary, the simulation is generally used to describe the conceptual or specification model of the real system when it is difficult to study it in usual methods.

1.4 Arena Program

The working simulation tool for the models in this project is Arena. In fact, Arena was chosen due to its convenient flowchart-modeling capability and vast built-in statistical analysis tools. Arena is a simulation environment consisting of module templates. Arena is built on top of a long-lasting simulation language called SIMAN. In essence, Arena represents SIMAN programming graphically and puts together commonly used combinations of blocks and elements from SIMAN to make an easy to use drag-and-drop simulation package (Merric and Hardin, 2004).

SIMAN consists of two classes of objects: blocks and elements. More specifically, blocks are basic logic constructs that represent operations; for example, a seize block models the seizing of a service facility by a transaction (referred to in Arena as “entity”), while a release block releases the facility for use by other transactions.

Elements are objects that represent facilities, such as resources and queues, or other components, used for statistics collection (Tayfur and Benjamin, 2007).

Arena maintains its modeling flexibility by being fully hierarchical as depicted in Figure 1.6. At any time we can pull in low-level models from blocks and elements panel and gain access to simulation-language flexibility and can mix in SIMAN construct together with the higher-level models from another template. For specialized needs, like complex decision algorithms or accessing data from external application,we also can write pieces of model in a procedural language like visual basic or C/C^{++} (Kelton and Sadowski, 1998).

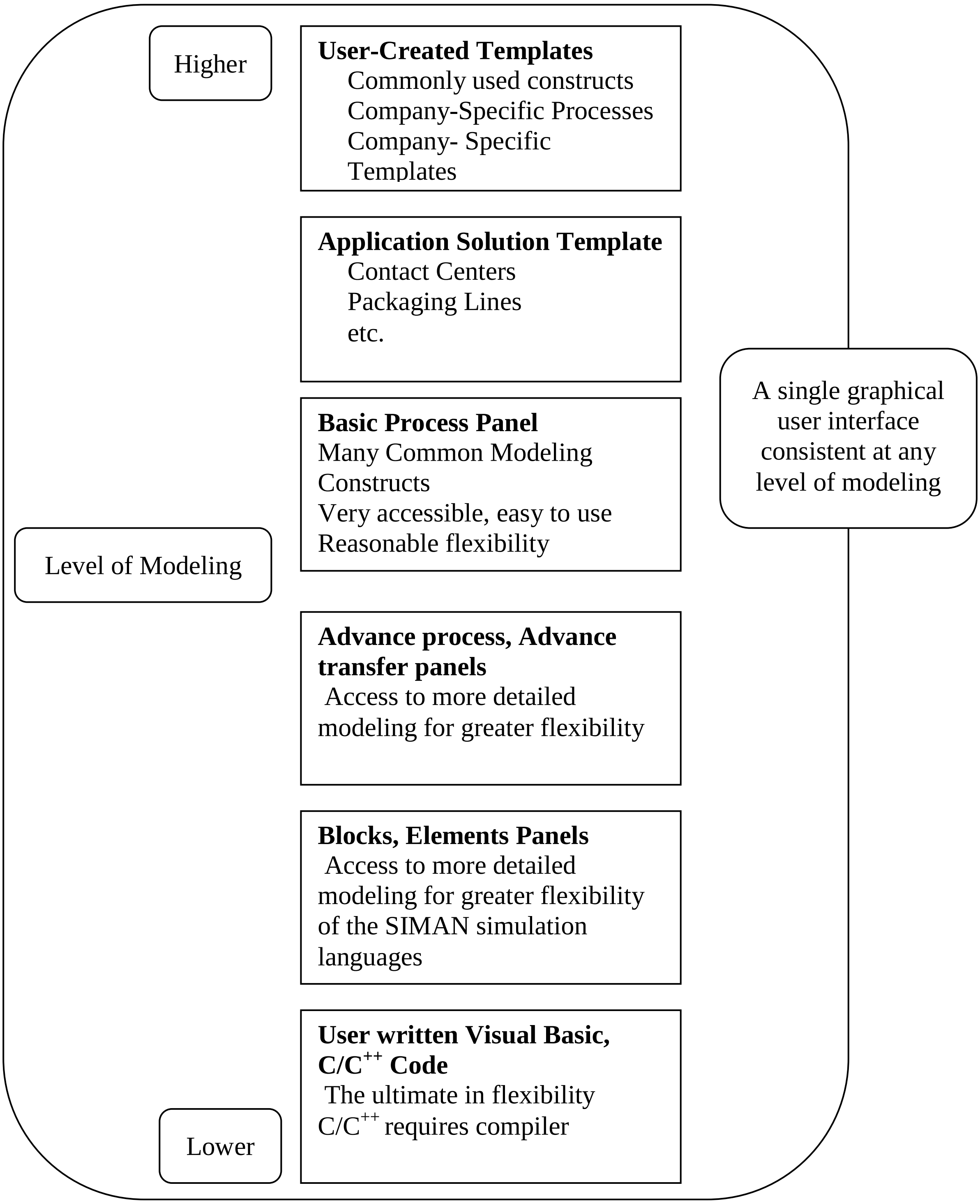

Figure (1.5) Arena's Hierarchical Structure (Kelton and Sadowski, 1998)

1.5 Research Objectives

1. To simulate the entrance and exit of pilgrims to Al-Masjid Al-Haram, which consist of queuing model by using Arena program and determined the peak hours.
2. To implemented methodology for building a mathematical model to the same kind of events.

1.6 Scope of study

The focus of this study is on understanding the Tawaf phenomena when a large number of pedestrians inter and exit from Al-Masjid Al-Haram during Hajj season. This study simulates only five main doors of Al-Masjid Al-Haram and the data collected from hajj season done in November 2010. The result would change for other seasons and doors.

1.7 Significance of the study

The research aim is to propose a simulation queuing model to the entrance and exit from Al-Masjid Al-Haram during Al-Hajj season in order to organize the entrance and exit to reduce the accidents that may happen in peak hours so we can encourage the pilgrims to use other doors in peak hours. In addition, we can use the same methodology in other crowded places such as football stadiums. The advantages of computer modeling and simulation are numerous that include controlled experimentation on an existing accessible real life scenario without disturbing the real life system.

1.8 Limitation of study

The study is limited to a small number of replications in the simulation, because we use an academic version of the Arena program. Increasing the number of replications in the Arena program needs a complete version of a program with a very high specification for the computer used in simulation.

1.9 Organization of Thesis

This thesis consists of five chapters, structured as follows: Chapter one presents the background and outline of the whole thesis construction. Chapter two gives an account of the literature of the three areas relevant to this study: Hajj studies, queuing model, and simulation modeling of pedestrians. The chapter starts with previous important studies on Al-Hajj movement. Section two displays the queuing congestion model in pedestrian networks, and an M/G/c/c state dependent in pedestrian networks. Section three presents the literature of simulation of pedestrians. Chapter three describes the research methodology. Chapter four displays the result and dissection for the simulation of entrance and exit. Chapter five displays the conclusions of this study and recommendations of future studies.

1.9 Summary

This chapter introduces the background of the study; models: approximations of real - world events, simulation, Arena program. The objectives and scopes of this study are listed in this chapter as well as its significance and limitation. The organization of thesis is laid out in this chapter. In the next chapter, the related literature will be reviewed.

Chapter Two

LITERATURE REVIEW

2.0 Introduction

In order to understand the problems and the shortcomings related to the Al-Hajj studies, queuing model and simulation of pedestrian, a considerable number of the past and recent literatures on these topics have been briefly reviewed in this chapter.

2.1 Al-Hajj Studies

This section shows the important publications on Al-Hajj studies during the last decades. Very limited works were directed to study the crowd behavior and movements of the pilgrims during Al-Hajj. Moreover, all researchers have studied Al-Hajj movement in only four locations:

1. The departure from Arafat to Mina (through Muzdalifah).
2. Stoning the devil at the Jamarat area.
3. The performance of “Sa’ee”, where pilgrims walk seven times between two hills.
4. The performance of “Tawaf” where pilgrims circumpolar seven times around the Ka’baa.

Al-Haboubi and Shokri (1997) suggested directing walking pilgrims along a path circling seven times around the Ka’aba. This model was developed for minimizing the total waiting time in the system as a function of width of spiral path and the level of service. The optimal width of spiral when the population increase was also determined.

Reda and Yamani (1998) proposed a macroscopic dynamic simulation model by using dynamo languages for studying the different types of pilgrim's movement.

Al-Haboubi (1999) applied the original function for maximizing the flow of the pilgrims per hours and minimizing the transportation costs.

Al-Haboubi (2003) presented a new design for solving the safety problems, by means of installing uni-directional lanes (one meter wide) and to restrict throwing to a circular zone up to 15 meters in radius. An experiment was conducted to estimate the throwing time at each lane, and simulation model was used to estimate the waiting time as well.

Klüpfel (2005) showed three examples for the application of the pedestrian flow simulation and analysis: Al- Hajj to Makkah, the World Youth Day 2005 in Cologne, and the egress (non-emergency) from a football stadium. For Al-Hajj to Makkah a model was made to the bridge of Jamarat area and the data were used to calibrate the model and then simulations were performed to support the planning for the improvement of the structures. Thus, by comparing the performances of different procedures and operation, guidelines can be formulated.

Koshak and Fouda, (2008) explored the use of GPS and GIS for analyzing and understanding the pedestrian movement pattern in Tawaf areas. Firstly, spatial-temporal data were collected by trained students using GPS devices at different times. Secondly, GIS allowed spatial-temporal analysis of collected data. In this paper they can determine the pedestrians average speed in different zones in the courtyard on each day of Hajj season.

Zainuddin et al., (2009) presented the governing equations for the Social Force Model. In addition, comparative studies were done for various kinds of microscopic pedestrian simulation models, highlighting the advantages as well as the disadvantages of each single model. Computer simulation software SimWalk and one of its applications for simulating the circumambulation of Ka'aba had been briefly discussed. Two studies in circumambulating the Ka'aba were implemented by Al-Haboubi and Shokri (1997): the first method was (the method from the study of (Al-Haboubi and Shokri, 1997)) which suggested a building of spiral path with panels to circumambulate the Ka'aba, while the second method was by plotting the waiting points around Ka'aba which directs pilgrims to walk around Ka'aba without building any panels. Simulation results reveal that the building of the spiral path is an effective and convenient pathway for ensuring the smooth flow, comfortable and safe conditions during the circumambulation of the Ka'aba.

Sarmady et al. (2010) presented a cellular automata model for the simulation of the pilgrims' circular Tawaf movement. In this case, the discrete-event model was used for simulating the actions and behaviors of the pilgrims. The proposed models were used in a software platform to simulate the actions and movements of pilgrims in the area. An example application of the model was tested in predicting whether specific changes to the architecture could increase the throughput of the system.

2.1.1 Summary

Table 2.1 Short summary for review in Al-Hajj studies

Author / Date	Problem	Description
Al-Haboubi and Shokri (1997)	Pedestrians crowded in Tawaf area	suggested directing walking pilgrims along a path circling seven times around the Ka'aba.
Reda and Yamani (1998)	Pilgrims movement problem in Holy city Makkah	Build a macroscopic dynamic simulation model by using dynamo languages for studying the different types of pilgrim's movement.
Al-Haboubi (1999)	Transportation problem during the pilgrimage season to Makka	A mathematical model is developed to maximize total flow of the pilgrims per hours and minimizing the transportation costs.
Al-Haboubi (2003)	Safety problem in Jamarat area	Installing uni-directional lanes (one meter wide) and to restrict throwing to a circular zone up to 15 meters in radius and used simulation model to estimate the waiting time as well.
Klüpfel (2005)	Safety problem in Jamarat area	Model was made to the bridge of Jamarat area and the data were used to calibrate the model and then simulations were performed to support the planning for the improvement of the structures.
Koshak and Fouda (2008)	Pedestrian movement pattern in Tawaf areas	-Explored the use of GPS and GIS for analyzing and understanding the pedestrian movement pattern in Tawaf areas. - Determine the pedestrian average speed in different zones in the courtyard on each day of Hajj season.
Zainuddin et al., (2009)	Pedestrians crowded in Tawaf area	Governing equations for the Social Force Model.
Sarmady et al. (2010)	Pedestrians crowded in Tawaf area	Cellular automata model for the simulation of the pilgrims' circular Tawaf movement.

2.2 Queuing model

In recent years, the congestion and finite capacity queuing system is considered one of the worldwide facts of modern life. Therefore, in this section, the definition and historical development of queuing system, congestion model in pedestrian networks, and M/G/c/c state dependent in pedestrian networks studies will be reviewed.

2.2.1 Definition of Queuing Theory

Queuing theory is the mathematical study of waiting lines, or queues. The theory enables mathematical analysis of several related processes, including arriving at the queue, waiting in the queue, and being served at the front of the queue. The theory permits the derivation and calculation of several performance measures including the average waiting time in the queue or the system, the expected number waiting or receiving service, and the probability of encountering the system in certain states, such as empty, full, having an available server or having to wait a certain time to be served (Gross and Harris, 1985).

2.2.2 Historical Development of Queuing Theory

The origin of queuing theory can be traced back to early in the last century when Erlang, a Danish engineer, applied this theory comprehensively to study the behavior of telephone networks. Acknowledged to be the father of queuing theory, Erlang had developed several queuing results that still remain the backbone of queuing performance evaluations today (Hock and Hee, 2008). After 1951, important work has been done in waiting line theory in order to apply the queuing theory for various problems come across in the industries and society. (Kendall,1953) has given a systematic and mathematical approach to waiting line problem. In 1971, Millins and Fry had developed the theory (Murthy, 2007), and now it has been widely used in different areas.

2.2.3 Congestion model

Tregenza, (1976) presented the curves on various experimental studies that relate the walking speed to crowd density. Furthermore, some needed information in designing the movement of the people in buildings was collected. One of the chapters was dedicated to the design of corridors, which is closely related to the current work. It also identified several factors associated with differences in mean walking speed namely, age and sex difference, groups, trip purpose, baggage, gradient, differing flow directions and density. The effect of crowding on walking speeds has been measured in several surveys such as when the density increases, the average speed becomes less, walking is reduced to a shuffle at a mean density of 3 ped/m^2 and forward movement is halted at about 5 ped/m^2. Empirical curves relating walking speed and density that showed variation of mean walking speed with crowd density based on the survey done on different places such as city centre footway, footways of shopping streets, fire escapes and subways. It was also stated that at below concentration of 0.3 ped/m^2, interaction between pedestrians is not obviously apparent to those involved and individuals are able to select their own walking speed. A density of 1.4 ped/m^2, most people tend to walk at less than their natural speed and will be aware of uncomfortable crowding.

Cruz and Smith, (2003) found that networks of M/G/C/C state-dependent queuing are important tools to model congestion. The main purpose was to verify whether or not M/G/C/C state dependent queuing networks are a reasonable choice to modeling similar configurations. In other words, the experimental evidences in favor of the departure process were provided from an M/G/C/C state dependent queue is Poisson. Since, the service times are a complex function of the number of users in the system, the stochastic process beneath the departure process is not well known even under Markovian arrivals. By using a discrete-event simulation approach, some insights into the output process of such systems evidencing that an exponential inter departure time maybe a reasonable assumption. Since practical systems may need a complex arrange of M/G/C/C queues configured in arbitrary topologies, including series, merges and splits. Simulation results indicated that the inter departure times maybe fairly assumed as exponentially distributed.

Cruz, et al., (2005a) presented a new methodology for approximate analysis of open M/G/C/C state-dependent queuing networks. They presented an empirical study upon the inter-departure process between the queues of the network and discussed an original application to network evacuation of high-rise buildings. The method is a combination of repeated trials and node-by-node decomposition approximation methods. The simulation model was also used to analyze the problem of evacuation of a ten-story buildings and the results indicated that the simulation model is an extremely valuable tool when planning emergency egress for buildings.

Cruz et al., (2005b) extended the development of algorithms for optimal service and capacity allocation in M/G/c/c state-dependent queuing networks, for a fixed generic network topology. In particular, the interest lies in pedestrian network applications, configured as a generic combination of basic series, merge, and split topologies as illustrated. Furthermore, a mathematical programming formulation for the service and capacity allocation (SCA) problem was presented, and the analytical stochastic model was used to describe pedestrian flows. Computational experiments with the proposed algorithm have been used to illustrate the usefulness of the optimization algorithm in evacuation problems for a ten-story buildings evacuation network.

Cruz and Smith (2007) studied the congestion in most practical situations. A methodology for approximate analysis of open state-dependent M/G/c/c queuing networks was described in which the service rate is subjected to the congestion as a function of the number of customers in the system. An empirical study upon the inter-departure process between the queues of the network was presented and discussed the original application to network evacuation of high-rise buildings was discussed. The published generalized expansion method (GEM) was successfully used to approximate performance measurements in network of queues. The GEM is a combination of repeated trials and node-by-node decomposition approximation methods, with a key characteristic that an artificial holding node is added preceding each finite queue in the network in order to register blocked customer that attempt to enter the finite node when it is at capacity. Computational experiments were performed and assumed homogeneous (small length) queues. The simulation results confirmed the accuracy of the estimates, being the analytical approximate results mostly within the 95% confidence interval. Computational results demonstrate that the methodology provides accurate results in many topological configurations as well as in the analysis of the network evacuation problems in high-rise buildings.

Osorio and Bierlaire, (2009) presented an analytic queuing network model, which preserves the finite capacity of the queues and uses structural parameters to grasp the between-queue correlation. Additionally, congestion is directly modeled via a novel formulation of the state space of the queues which explicitly captures the blocking phase. The model can describe the sources and effects of congestion. The model was formulated for networks with an arbitrary topology, multiple server queues and blocking-after-service. It was validated by comparison with both pre-existing methods and simulation results. The model was applied to study patient flow in a network of units of the Geneva University Hospital. The model had facilitated the identification of three main sources of bed blocking and able quantify their impact upon the different hospital units.

Cruz et al. (2010) presented a version of the system optimum model in which the travel costs incurred on each path come from M/G/c/c state-dependent queuing networks, a stochastic travel time estimation formula which takes into account congestion effects. A differential Evolution algorithm was proposed to solve the model.

Richard (2010) examined a discrete-time queuing system with applications to telecommunications traffic. The arrival process is a particular Markov-modulated process which belongs to the class of discrete batched Markovian arrival processes. The server process is a single server deterministic queue. A closed form exact solution is given for the expected queue length and delay. A simple system of equations is given for the probability of the queue exceeding a given length.

2.2.4 Summary

Table 2.2 Short summary for review in Al-Hajj studies

Author / Date	Queue System	Description
Cruz and Smith, (2003)	M/G/C/C state-dependent queuing	Proved networks of M/G/c/c state-dependent queuing are important tools to model congestion.
Cruz, et al., (2005a)	M/G/C/C state-dependent queuing networks	The problem of service and capacity allocation in state-dependent M/G/c/c queueing networks is analyzed and algorithms are developed to compute the optimal allocation c.
Cruz et al., (2005b)	M/G/c/c state-dependent queuing networks, for a fixed generic network topology	A discrete-event digital simulation model developed to study traffic 1ows in M=G=C=C state-dependent queuing networks.
Cruz and Smith (2007)	open state-dependent M/G/c/c queuing networks	Described a methodology for approximate analysis of open state dependent *M/G/c/c* queuing networks in which the service rate is subject to congestion.
Osorio and Bierlaire, (2009)	Analytic queuing network model	Presented an analytic queuing network model, which preserves the finite capacity of the queues and uses structural parameters to grasp the between-queue correlation. The model was applied to study patient flow in a network of units of the Geneva University Hospital.
Cruz et al. (2010)	M/G/c/c state-dependent queuing networks	Presented an overview of the traffic assignment problem in urban networks.
Richard (2010)	Markovian	A discrete-time queuing system with applications to telecommunications traffic.

In this project we used M/G/c/c model which is considered an important tools to model congestion all the details will be explained in chapter 3.

2.3 Simulation

Simulation is one of the important techniques used to solve problems that are difficult to be solved by the analytical or numerical methods. In simulation, we use a computer to evaluate a model numerically over a time of interest, and data are gathered to estimate the desired true characteristics of the model. In this section, we give some important information about simulation and modeling and review the past studies.

2.3.1 Definitions of simulation:

- Simulation is the art and science of creating representation of a process or system for the purpose of experimentation and evaluation (Gogg, 1993)
- Simulation is a numerical technique for conducting experiments on a digital computer, which involves certain types of mathematical and logical models that describe the behavior of business or economic system (or some component thereof) over extended periods of real time (Naylor, 1996).
- Simulation is one of the most powerful techniques available for solving problems. It involves the construction of a replica or model of the problem on which we experiment and test alterative courses of actions (Pool and Szymankiewic, 1997)
- Simulation is a means of experimenting with a detailed model of real system to determine how system will respond to change in its structure, environment or underlying assumption (Harrington and Tumay, 2000).

- A simulation is the imitation of operation of real- world process or system over time. It's involves the generation of an artificial history of system (Banks, 2000).
- A simulation is an imitation of a real world system or process. Computers used to handle the necessary computation allowing concentrating on building valid model and analyzing them to get the answer (Merric and Hardin, 2004).
- Simulation is the use of system model that has designed characteristic of reality in order to produce the essence of the actual operation (Murthy, 2007).
- Simulation is a techniques used to evaluate the behavior of the system under different sets of conditions by using models to carry out groups of experiments (Tayfur and Benjamin, 2007).
- Simulation is the possibility of performing experiments on model instead of the real system corresponding to the model, the mathematical model is represented in executable from computer (Fritzson, 2003).

In the end we can give a simple definition "Simulation is the perform experiments using computer implementation of the model".

2.3.2 History of Simulation

Simulation was firstly used in the defense industry in the 1950 (Harrington and Tumay, 2000). In the early years, simulation was a conducted in FORTRAN or other general purpose programming language without the support of simulation specific routines (Banks, 2000). During 1960s, the using of simulation was expanded to other purpose and the computer language was developed to SIMSCRIPT, GPSS, SLAM and the forerunners of the simulation programming (SPLS) (Banks, 2000).