A SIMULATION MODEL FOR THE SHUTTLE BUS TRAFFIC DURING NAFRAH PERIOD

BY

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A Thesis Presented to the

DEANSHIP OF GRADUATE STUDIES

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

DHAHRAN, SAUDI ARABIA

In Partial Fulfillment of the

Requirements for the Degree of

MASTER OF SCIENCE

In

SYSTEMS ENGINEERING

MARCH 2001

UMI Number: 1406100

UMI Microform 1406100

Bell & Howell Information and Learning Company
300 North Zeeb Road
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DEANSHIP OF GRADUATE STUDIES

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عمادة الدراسات العليا
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To my dear parents

ACKNOWLEDGEMENT

In the name of ALLAH, The Most Gracious and The Most Merciful

First and foremost, all praise to ALLAH *subhana-wa-ta'ala,* The Almighty, The Creator and The Sustainer of the Universe, Who granted me the grace and the strength to complete this work. Peace and blessing of ALLAH be upon His last Prophet Mohammad *sallallaho-alaihe-wassalam.*

Acknowledgement is due to King Fahd University of Petroleum and Minerals for the support in carrying out this research.

I take deep pleasure in expressing profound gratitude to my thesis advisor Professor A. A. Andijani for his valuable guidance, patient hearing, and continuous support throughout the course of this study. My heartily thanks are also due to my thesis co-advisor Professor S. O. Duffuaa for his remarkable assistance and patience throughout the work. I would like to thank other committee members: Professor M. Ben-Daya, Professor S. Z. Selim, and Dr. U. Al-Turki for their help and co-operation. They gave suggestions that made this work even better.

I'm please to appreciate the support and help provided by the Ministry of Hajj. Thanks are due to H.E. Dr. S. Al-Sabban, Deputy Minister, and H. E. Dr. M. Benton, Assistant Deputy Minister for their keen interest in research efforts serving Hajj.

I also wish to express my appreciations to Mr. Turki Al-Qurashi for the considerable assistance, and data he provided .

Special thanks goes to my parents, my wife, my daughter, my brothers, my sisters, and my friends for their encouragement and support.

Although some people didn't contribute directly to this effort, I still would like to acknowledge their role. I owe special thanks to Dr. Ibrahim Okair , at University of Khartoum for his generous support and valuable encouragement. I would also like to thank my Sudanese brothers at KFUPM who made my stay over here memorable, and joyous.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

خلاصة الرسالة

الاسم : محمد الحسن سليمان

العنوان : "نموذج محاكاة لحركة الحافلات الترددية خلال النفرة"

التخصص : هندسة النظم

تاريخ الشهادة : مارس ٢٠٠١م.

يمثل موسم الحج أحد أضخم التجمعات البشرية في العالم حيث يتجمع ما يربوا على مليوني حاج لأداء فريضة الحج كل عام. ظاهرة الازدحام المروري خلال الحج تعتبر معضلة وتزداد عسراً خلال نفرة الحجيج من عرفات إلى مزدلفة ليلة العاشر من ذي الحجة. في هذه الدراسة تم تطوير نموذج تصوري لحركة الحافلات الترددية خلال النفرة. النموذج يمثل العناصر الرئيسية لهذه المشكلة. بعد ذلك حوّل النموذج التصوري إلى نموذج محاكاة حاسوبي باستخدام حزمة المحاكاة بروموديل. تم التحقق من صحة النموذج باستخدام البيانات المتوفرة عن تجربة النقل بالحافلات الترددية عام ١٤١٦هـ. ومن ثم تم استخدام النموذج لتحديد عدد محطات الإركاب والمسافات بينها، وعدد الحافلات التي تحقق أفضل أداء لنظام النقل الترددي على الطريق رقم ٩. وقد استخدم في قياس أداء النظام عدة مقاييس هي سرعة إخلاء عرفات، مستوى الزحام، ومتوسط زمن الرحلة, تبع ذلك تمديد النموذج إلى بقية طرق النفرة. تمت موازنة الحركة على شتى الطرق على أساس سعة كل طريق والخطة المتبعة في تخصيص المخيمات بعرفات، دلت الدراسة على أنه يمكن إخلاء عرفات خلال ست ساعات باستخدام ٣١٦٠ حافلة ترددية.

ماجستير في العلوم

جامعة الملك فهد للبترول والمعادن

الظهران – المملكة العربية السعودية

مارس ٢٠٠١ م

THESIS ABSTRACT

FULL NAME	MOHAMED ELHASSAN SELIAMAN
TITLE OF STUDY	A SIMULATION MODEL FOR THE SHUTTLE BUS TRAFFIC DURING NAFRAH PERIOD
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Hajj is one of the world's largest mass movements, where over two million pilgrims converge every year at the same time to perform this religious duty. Traffic congestion during Hajj is a phenomenal problem. It is more severe during Nafrah, which is defined as the movement of pilgrims from Arafat to Muzdalifah during the 10^{th} night of the twelfth month of the lunar year. In this work a conceptual model has been developed for the shuttle bus traffic during Nafrah. The model represents the main elements of this important problem. Then model has been transformed into a simulation model using Promodel simulator. Verification and validation for the model have been carried out using data from 1416H shuttle bus experiment. Then the model has been used to determine the number of bus stops ,bus stops spacing , and the fleet size that can achieve best values for the performance of the shuttle bus system on road 9. Arafat evacuation time, the congestion level, and the average travel time are the performance measures used. Following this, the model has been extended to the remaining Nafrah roads. The traffic on the different roads has been balanced according the capacity of each road and the current plan of allocating camps at Arafat . It has been shown that using a shuttle bus system Arafat can be evacuated in at most 6 hours when only 3160 buses are used..

MASTER OF SCIENCE DEGREE

KING FAHD UNIVERSITY OF PETROLEUM AND MINERALS

DHAHRAN, SAUDI ARABIA

MARCH 2001

Chapter One

Introduction

1.1 Introduction

Hajj or Muslims pilgrimage to Makkah is the largest mass gathering in the world within the prescribed time and space limits. The Hajj consists of a set of prescribed religious (Islamic) rituals on specified dates at specified hours in assigned locations in and around Makkah. Ritual of hajj starts when a pilgrim enters the state of Ihram before entering the holy city of Makkah. In this state the pilgrim must obey a number of restrictions including not cutting his hair or nails, not using scent or cosmetics, not killing non-dangerous animals, abstaining from sexual intercourses, etc., as well as wearing special cloths of Hajj consisting (for men) of two pieces of seamless, white cloth, one covering the body from waist to uncles and the other worn over the pilgrim's shoulder; women must wear a simple dress of white and a veilless head covering. Upon arriving into Makkah the pilgrim has to perform the rite known as the Tawaf, or the circumambulation of the Kaaba seven times, and Sa'y retracing the steps of Hagar seven times between the two hills of Safa and Marwa.

On the day of eight Dhul-Hajja the pilgrims travel to mina, a site outside Makkah where special camps are pitched for this event. On the morning of the ninth day pilgrims leave

Mina and move towards Arafat, located on the flat, sand desert floor. All pilgrims must be in Arafat before sunset to have a valid Hajj. They stand from noon to sunset in a rite known as Wukuf. After sundown they proceed back towards Mina stopping at Muzdalifah; in the Hajj this movement known as Nafrah. Then on the tenth of Dhul-Hajja they return to Mina where they throw small stones at the Jamarat, i.e. symbols of the devil. Following this some of them carry out the animal sacrifice. All pilgrims are supposed to stay in until the noon of the twelfth day to stone the Jamarat on the eleventh and twelfth days. During this time they may go to Makkah and perform Sa'y. It is optional for them to stay one more day and stone the Jamarat. Performing a final Tawaf completes the rituals of Hajj. Figure 1.1 shows the map of the holy sites. After one month, majority of pilgrims leave Makkah. After three months virtually all the pilgrims coming from outside Saudi Arabia leave to their homelands. Today, with the fast jet aircraft transport conveys hundreds of thousands of pilgrims speedily to the Kingdom, the convenience and other advantages of the services (e.g. greater security, air conditioning even in the tents, health services, etc.) provided for pilgrims in the holey sites, and the expansion of the Islamic world, the masses of pilgrims are enormously increasing.

Each year about 1.5 to 2.5 million pilgrims gather from all over the world and converge at Makkah to perform this religious duty simultaneously. The result is a crowded event of extraordinary magnitude leading to uniquely challenging in problems in terms of traffic congestion, accidents, health disbenefits, air pollution, noise, and other environmental consequences. Traffic congestion is one of the most severe problems during Hajj season. The holy sites of Arafat, Muzdalifa and Mina are geographically limited. Traffic jams

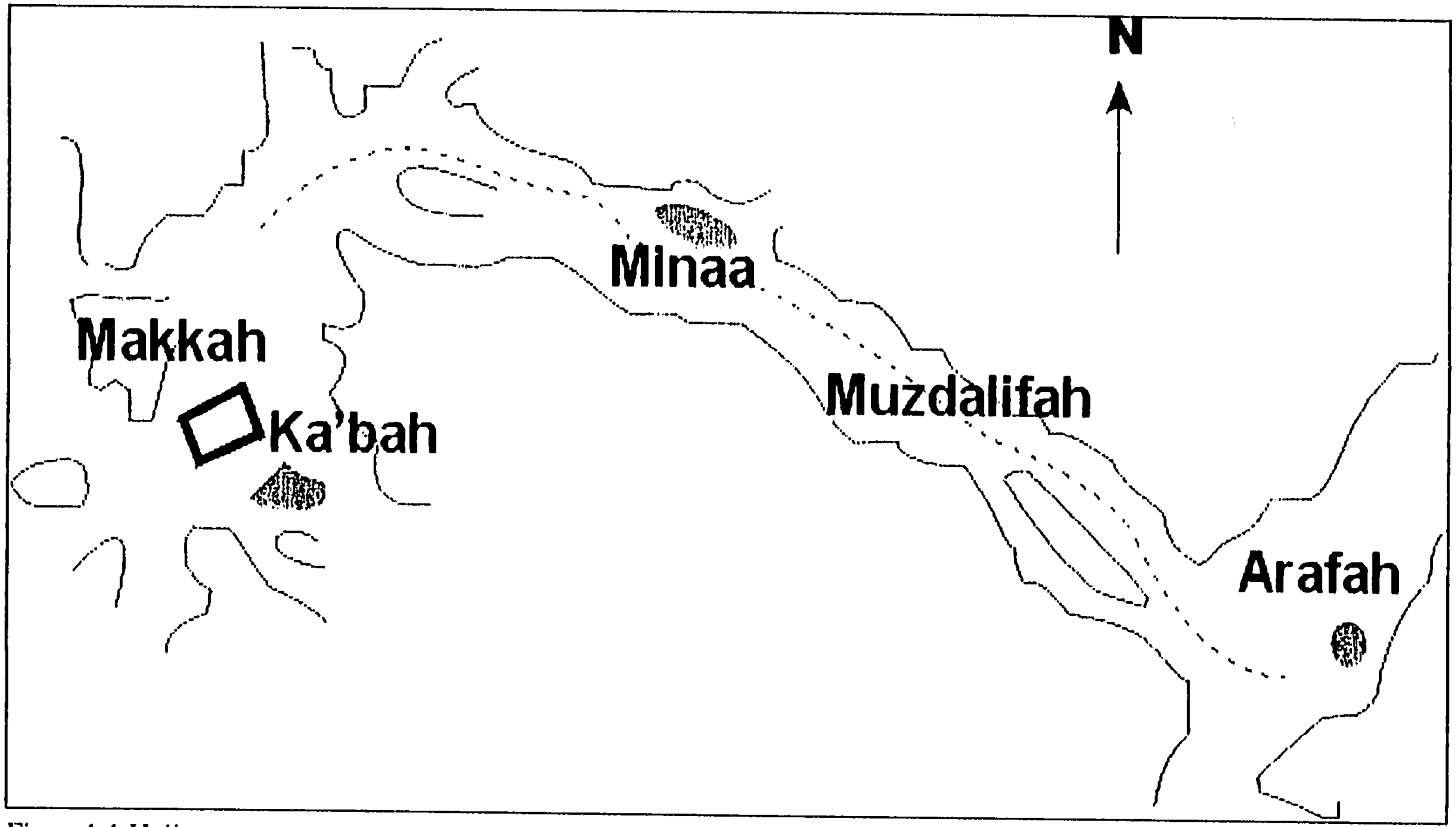

Figure1.1 Hajj map.

and bottlenecks can turn into disasters or at least disturb the pilgrim's movement. One of the most difficult such traffic problems is the Nafrah movement.

1.2 Nafrah

Nafrah is defined as the movement of the pilgrims from Arafat after sunset, to Muzdalifah. The duration of Nafra is from the ninth to the dawn of the tenth day. Its time span is approximately ten hours. On the ninth of the Dhul-Hajja (also called as the day of Arafat), pilgrims gather and stand in the plains of Arafat from noon to sunset. After the sunset, everybody has desire to move to Muzdalifah about eight kilometers to the west. Arafat and Muzdalifa are connected with nine roads for vehicles and two roads for pedestrians. Regular buses, mini-buses and small cars of capacity nine passengers are the type of vehicles used to move the pilgrims. The vehicles move in a mixed traffic mode. The pedestrians are also mixed with the vehicles during the movement in Arafat and probably later on the way to Muzdalifah. Arriving at Muzdalifah pilgrims collect pebbles to throw at the Jamarat pillars on the following day. Some of the pilgrims spend the night at Muzdalifa before leaving to Mina, about 4 kilometers to the west, while some of them leave to Mina during the night. Vehicles follow six roads connecting Muzdalifa to Mina while pedestrian lanes converge at the borders of Muzdalifa forming one lane passing to Mina. This movement of pilgrims is unique in nature and characteristics. It is now commonly accepted that trying to solve the traffic problems by constructing new roads or adding new facilities will not work and unacceptable. The existing network is sophisticated one and has received as much enhancement as the spatial and geographical constraints permitted. Road building is expensive, damaging to the environment, and expected to induce extra traffic that negates all the benefits produced by their construction, see Downs [14].

An alternative approach to alleviate traffic congestion is to have the management and planning of transportation system that helps make use of the existing infrastructure more efficiently. Traffic simulation model are becoming increasingly popular for the evaluating and planning traffic systems, and application area where the use of analytical tools, though very important, is limited. The reasons to use simulation in the field of traffic are the same as in all simulations; demonstrate a proposed course of action before implementation, to make research, to evaluate alternatives, and to learn.

1.3 Thesis Objectives

The overall objective is to develop a stochastic simulation model for the shuttle bus traffic during Nafrah period. This will include the following steps:

1. Define the problem in the context of the shuttle bus system.
2. Establish clear objectives for the simulation model.
3. Construct the simulation model.
4. Test and validate the model.
5. Use the model to determine the following:
    a. Locations of the bus stations at Arafat and Muzdalifah.
    b. The number of buses that achieves best value for the performance measures(evacuation time, average travel time, and congestion level).
    c. Finding the level of service that achieves best value for the performance measures.

1.4 Methodology

In this work a conceptual model that represent the traffic flow during Nafrah will be developed. The conceptual model will include traffic handling in Arafat, traffic modeling on routes between Arafat and Muzdalifah and unloading in Muzdalifah. Then the conceptual model will be transformed into a simulation model. The model will be used to assess the impact of dedicating the exiting road network for the shuttle bus operational strategy. In addition the model will be used to address various traffic management and control policies during Nafrah period.

1.5 Definitions

Evacuation Time

Is the elapsed time between the start of Nafrah and the arrival of last group of pilgrims from Arafat to Muzdalifah.

Average Travel Time

The average time taken by a bus to traverse the distance between Arafat and Muzdalifah.

Traffic Flow

The number of buses that pass a point on a highway, or a given lane or direction of a highway, during a specified time interval.

Free Flow Speed

The maximum speed which corresponds to the lowest density level.

Jam Density

The maximum number of buses that can be accommodated in a length of roadway, this corresponds to the zero flow situation.

Level of Congestion

Level of congestion is related to the number of buses on the road at any given time. A good measure of the level of congestion is the traffic density at any given time.

Average Delay

Average delay is average time pilgrims wait at Arafat before they are taken by a bus to Muzdalifah.

1.6 Thesis organization

Chapter 1 of this thesis provides a brief description of the most important aspects of the hajj, with a particular attention to the Nafrah movement. The objectives of the work, the research methodology, and the structural overview are all presented in this initial chapter.

Chapter 2 provides a concise statement of the Nafrah transportation problem. This chapter also aims to give definitions for basic traffic stream parameters and literature review.

Chapter 3 addresses the development of the Nafrah conceptual model. The basic elements of the model are described.

Chapter 4 focuses on the development of the simulation model, traffic modeling, model verification and validation, and the results obtained for road nine.

Chapter 5 is dedicated for the presentation of the comprehensive model for Nafrah and balancing the traffic on the different roads.

Finally, chapter 6 contains the concluding remarks along with suggestions for future research work on the Nafrah transportation problem.

Chapter Two

Problem Statement and Literature Review

2.1 Introduction

This chapter presents the important aspects of Nafrah transportation problem, statement of the problem, traffic stream parameters, and review of related literature. The chapter is organized in four sections. Section2.2 introduces the Nafrah transportation problem, the conventional transportation system, the domain of the problem, and the shuttle bus operational strategy. Section 2.3 deals, briefly, with the fundamental characteristics of traffic flow. Section 2.4 contains the review of literature on Hajj transportation problem and traffic simulation models.

2.2 Nafrah Transportation Problem

Nafrah transportation problem today constitutes one of the most severe problem of hajj. Since Hajj involves the movement of 2.5 million pilgrims – this number is expected to jump above 4 million- a unique transportation problem is presented, since all of them attempt to travel in the same direction, in the same movement corridors, and all in the same single peak period.

Realizing the dimension of the Hajj problems, the government of Saudi Arabia established the Custodian of two holy mosques institute for Hajj research, which studies problems associated with the Hajj. During the peak of the Hajj season the government puts all its resources to manage this complex problem. In addition, the Ministry of Transportation held several symposiums as a response to the real need for intensive research on planning and managing transportation and traffic safely, comfortably and in the shortest possible time.

2.2.1 Domain of the Problem

The problem of moving the pilgrims during Nafrah period has time and space constraints. The time constraint is a religious requirement. The space constraint consists of Arafat, Muzdalifah, and the road network. These constraints will be described next.

The time constraint

The Nafrah time constraint requires that all pilgrims start to move from Arafat at the sunset of ninth day of the Dhul-Hajja and must be in Muzdalifah by the dawn of the tenth.

Arafat road network and parking space

The area of Arafat is divided into rectangular pieces of land by a grid of streets. The main streets are running east west while minors are running north south. There is an outer ring road surrounding Arafat at its legal boundaries. Parking lots that are available in Arafat can accommodate more than 8000 vehicles. Figure 2.1 shows Arafat road network.

Muzdalifah layout

The space and parking availability at Muzdalifah is a critical element for smooth traffic and timely evacuation of Arafat. Each road passing through Muzdalifah has several parking lots. These parking lots found in Muzdalifah can accommodate more than 7000-parked vehicles.

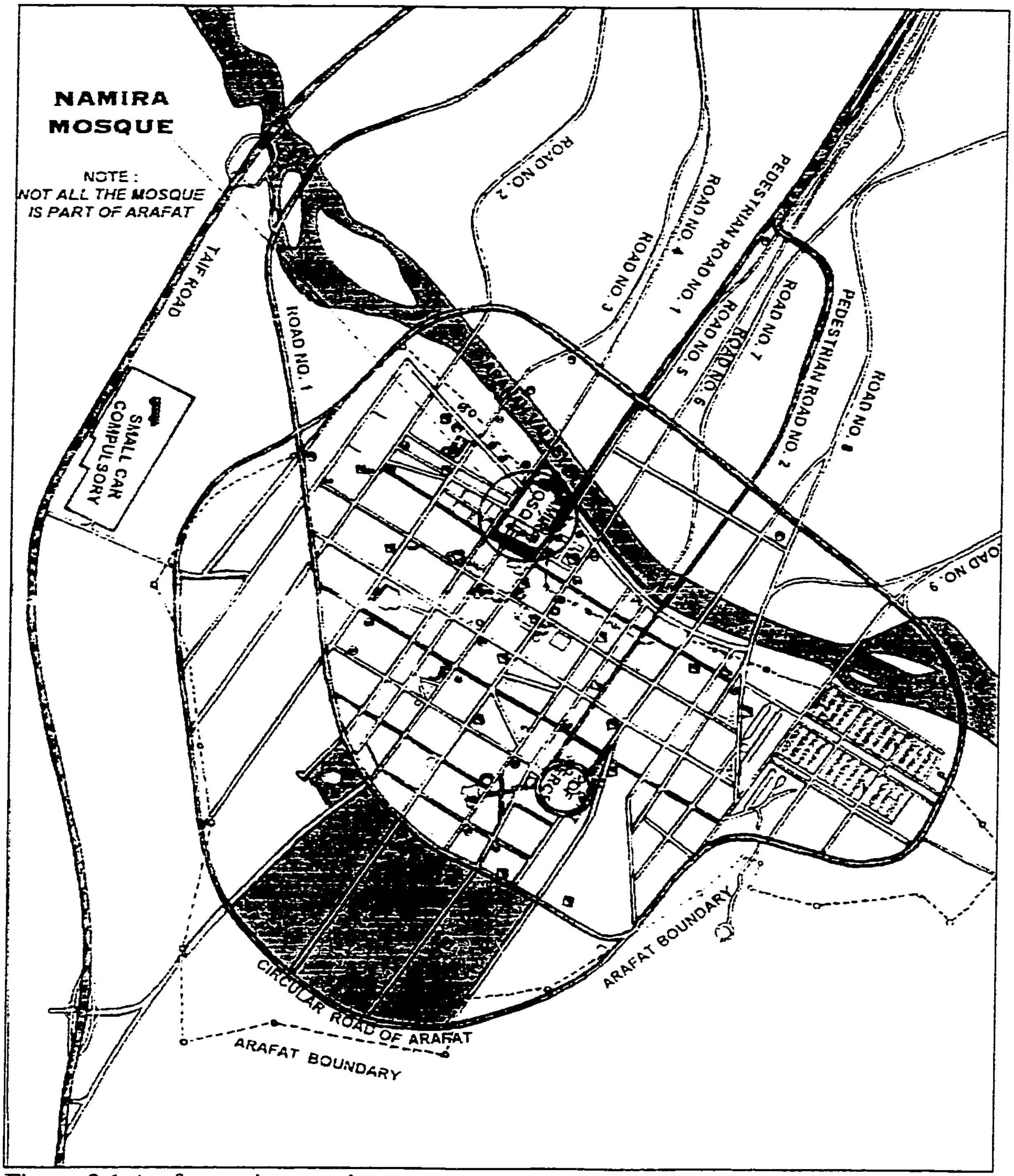

Figure 2.1 Arafat road network

Therefore the problem under consideration is to transport the pilgrims safely during Nafrah period in the required time with minimum congestion, utilizing the exiting road and parking network.

2.2.2 Conventional Hajj Transport System

Each service organization, handling pilgrims from outside is assigned a bus for every hundred pilgrims. The total number of buses used to transport outside pilgrims (one million) is about twelve thousand buses. On the other hand, the number of vehicles used by pilgrims from within the kingdom (one million) is about forty thousand. After sunset all vehicles use the exiting road networks to travel towards Muzdalifah. Table 2.1 shows a typical distribution of pilgrims from outside, number of buses for the use of each group, and the roads they use during Nafrah. The current practice is that buses are kept with the pilgrims during Nafrah and only few buses return to Arafat. This practice leads to extra traffic bottlenecks and jams, and makes it hard to control the traffic. This practice leads to extra traffic bottlenecks and jams, and makes it hard to control the traffic. It is observed that most of the time, vehicles stop in queues and traffic flow drops to zero.

2.2.3 The Shuttle Bus Transportation System

The shuttle bus system is used to transport passengers between specific locations according to certain plans and schedules. Examples of shuttle bus transportation system can be found in airports, hotels and schools.

The shuttle bus operational strategy was experimented, in Hajj transport system, for the first time in 1416H. In that year a total of 117000 pilgrims were transported along an exclusive 2-lane bus way (Road number nine) using only 520 buses shuttling between Arafat and Muzdalifah. Compared to the conventional Hajj transport system, the shuttle

Table 2.1 distribution of foreign pilgrims

Pilgrims (Organization)	**Number of pilgrims**	**Number of buses used**	**Road used**
Africa	90,000	900	2
Arabs	260,000	2600	6 & 7
Iranian	90,000	1800	8
South Asia	300,000	3000	4 &5
South east Asia	250,000	2500	2
Turkish and Europe	140,000	1400	9
Total	1,130,000	12200	8 roads

bus system resulted in much less average travel times (20min. vs. 195 min) and less bus fleet size (520 buses vs. 1270 buses) Elbar [5]. Being encouraged by the success of this experiment, the shuttle bus operational strategy was used in the following years to transport pilgrims along the same road (road number nine).

Implementing shuttle bus system for Hajj transportation is based on assigning separate paths for buses in order to allow for pure bus traffic along the roads. The buses are supposed to transport pilgrims from one shrine to another and return to the first shrine using the same road, to move other pilgrims. The fleet size is determined according to road network capacity to achieve a good level of service. The shuttle bus system has the following advantages

- It makes it easy to mange, and direct the traffic
- It helps in reducing the sufferings pilgrims feel during Nafrah, so that they concentrate on their worships.
- It helps in reducing the parking space at Arafat and Muzdalifah, and consequently save more space for other pilgrims' usage and services.
- It reduces the transport cost by reducing the number of buses used.
- Achieving high traffic flow rates and permitting for easy and safe motion for other vehicles used by civil defense parties, police men, ...etc.
- It helps in preserving the environment and reducing the air and acoustical pollution.

Implementing the shuttle bus operational strategy in Nafrah transport system has the following basic requirements

- Isolating a closed loop route on the road connecting the pilgrims' locations at Arafat and Muzdalifah.
- Assigning enough space outside legal boundaries of Arafat to use as center and store for the buses.
- Constructing bus stops (with suitable gates) at Arafat and Muzdalifah.
- Training the related entities such as service organizations, transportation companies, and the general security men.

2.3 Traffic Stream Parameters

This section deals, briefly, with traffic characteristics. The fundamental characteristics of traffic flow are rate of flow, speed, and density. These characteristics can be observed and studied at the microscopic and macroscopic levels, Daganzo [13]. These characteristics are defined below.

2.3.1 Flow Rate

Rate of flow, or traffic volume is defined as the number of vehicles that pass a point on a highway, or a given lane or direction of a highway, during a specified time interval. The unit for rate of flow is simply "vehicles," although it is often expressed as vehicles per unit time May [23].

2.3.2 Speed

Speed is the second principal parameter describing a given traffic stream. Speed is defined as a rate of motion, in distance per unit of time. It is the inverse of the time taken by a vehicle to traverse a given distance.

2.3.3 Density

The longitudinal vehicles in the traffic stream can represent the microscopic traffic density, which is defined as the number of vehicles occupying length of roadway. This characteristic is of particular importance considering safety, capacity, and level of service. Minimum space must be available in front of every vehicle so that the driver can control his vehicle without colliding with the vehicle ahead or with fixed objects on the roadway. The spacing of the vehicles on the other hand influences the capacity of the roadway and in turn affects the level of service. Vehicle spacing is also important from the point of view of level of service. If vehicle spacing is large, the driver has considerable freedom and a high level of service.

As the spacing decreases drivers are required to give more attention to driving task and may have to reduce their operation speed. This results in lower level of service but increased productivity as long as spacing remains greater than the critical spacing May[23]. If the spacing becomes less than the critical spacing, not only the does the productivity drop below the capacity level but the level of service becomes lower and lower.

The extreme case would be vehicle stopped in a queue where spacing would be minimum but the level of service would be the lowest and flow would be zero.

2.3.4 Time Headway

Time headway is defined as the elapsed time between the arrivals of pairs of vehicles. The time headway, h, consists of two time intervals: the occupancy time for the vehicle to pass the observation point and the time gap between the rear of the lead vehicle and the front of the following vehicle. In theory it is the elapsed time between the passage of identical points on two consecutive vehicles. However in practice the leading edges are used whether detectors take the measurements automatically or manually by observers. The time headway between vehicles is an important flow characteristic that affects the safety level of service, driver behavior, and capacity of a transportation system. A minimum time headway must always be present to provide safety in the event that the lead vehicle suddenly decelerates. The percentage of time that the following vehicle must follow the vehicle a head is one indication of level or quality of service. The distribution of time headways determines the requirement and the opportunity for passing, merging, and crossing. Under capacity-flow conditions, the minimum time headway and the time headway distribution govern the capacity of the system.

2.3.5 Distance Headway

Distance headway is defined as the distance from a selected point on the lead vehicle to the same point on the following vehicle. Usually, the front edges are selected, and hence the distance headway includes the length of the lead vehicle and the gap length between lead and following vehicle May[23].

2.4 Literature Review

2.4.1 Traffic in Hajj

Yafi [32] performed one of the most comprehensive studies in Hajj logistics. He provided an overview of the Hajj and its problems focusing on problems of internal Hajj movement. He developed a nonlinear model for this movement.

Bushnagh [11] presented the major characteristics and goals, which make the Hajj traffic system unique. He proposed some standard measures for the planning and assessment of this system.

Abdulghani [2] studied the basic movements of the pilgrims during the period from the 8^{th} to the 13^{th} of Dhulhajjah and the overall hajj transportation system objectives. He proposed a plan that encourages walking and improving the system efficiency.

Algadhi et al. [4] modeled the dynamics of crowd behavior in the Jamarat area by means of simultaneous differential equations. These equations were solved numerically and the model was used to examine the effect of different loading strategies and other possible control measures on the Jamarat system throughput.

Charnes et al. [12] developed a non-linear network model to minimize traffic congestion of holy sites. The developed model gave some insight in studying the effect of pilgrim's number on the Hajj situation under the system capacity.

Reda and Yamani [25] proposed a macroscopic dynamic simulation model using dynamo language to study the different types of pilgrim's movement.

Al-Haboubi [6] developed a mathematical model to increase the pilgrim's flow. Solving this model would help in determining the percent distribution for the various means of transportations used in Hajj.

AlGhadhi [5] used AIMSUN2 microsimulation package to assess the impact of dedicating some of the Nafrah highways to the shuttle bus operational strategy experimented on road nine. AIMSUN2 (Advanced Interactive Microscopic Simulator for Urban and Non-urban Networks) is developed for non-terminating simulation modeling while Nafrah traffic model is terminating simulation. In this work shuttle bus is not explicitly modeled, instead, the existing road network was simulated and then its performance was compared with the simulated performance of the network when the 4-lane road number 9 was removed. It was concluded that the removal of road nine (which is served by the shuttle bus system) did not drastically affect the performance of the Nafrah in general.

The simulation group of the systems engineering department at KFUPM [30] developed a simulation model for bus scheduling and routing during Nafrah period.

2.4.2 Traffic Simulation models

Road transportation, that is, efficient movement of people and goods through physical road and street networks is a fascinating problem. Traffic systems are characterized by a number of features that make them hard to analyze, control and optimize. The systems often cover wide physical areas, the number of active participants is high, and there are many system inputs that are outside the control of the operator and the participants (the weather conditions, the number of users, etc.).

In addition, road and street transportation systems are inherently dynamic in nature, that is, the number of units in the system varies according to the time, and with a considerable amount of randomness. The great number of active participants at present at the same time in the system means a great number of simultaneous interactions. In all, traffic systems are an excellent application environment for simulation based research and planning techniques.

Traffic simulation models are usually divided into two categories, according to the traffic flow theory approach used: the macroscopic models, which basically consider the traffic flow as a continuous fluid, and the microscopic models, which regard each particular vehicle and its interactions with other objects, Silva [31]. Microscopic models search the detailed representation of vehicle behavior. Originally most of them are based on the so-called car-following approach, developed to describe the relationship between the behaviors of two consecutive vehicles in a traffic stream. Furthermore, responses from the driver/vehicle to other stimuli occurring in the traffic environment also became an objective of microscopic modeling, this being eased by the increase in computing power.

Schulze and Flies [28] investigated the influence of various time-advanced methods in microscopic urban traffic models. Experiments were focused on simulation run times and results. The implemented event-oriented approach lead to significantly smaller run times than the time slice approach. The kind of time-advances approach influences the accuracy of the simulation results.

Lorenz et al. [21] described and compared two approaches aimed at largely automating the process of building rapidly executing micro-level simulation models for complex traffic networks. Preliminary results with the prototypes showed that it is possible to develop vehicle traffic simulators with favorable runtime performance characteristics.

Rao et al. [24] discussed the concept of validation and proposed an multistage validation framework for traffic simulation models. The validation results illustrated that the proposed validation procedure can account for the complexity of the validation task and its conclusions.

Schulz [27] describes different approaches for modeling streetcars and bus traffic systems. Models are applied to schedule street cars and buses, change times for passengers between different street car lines, change time between street cars and buses.

Esser and Schreckenberg [19] presented a microscopic simulation tool for urban traffic based on cellular automata. The model permits the simulation of large networks in multiple real-time.

Silva [31] described the nature and skills of some microscopic traffic tools, and analyzed their ability to adequately represent the bus behavior in urban environments. A number of bus operation models, mostly dealing with specific aspects of bus systems, was also considered.

2.5 Conclusion

In the recent years, traffic simulation has become one of the most used and powerful tools for the analysis and assessment of the transportation systems. This due to the ability of simulation to answer, " what if "questions helping in evaluating the impact of proposed changes on existing systems, or constructing new systems. This wide-ranging role of traffic simulation as systems analysis tool can be utilized to study the effect of certain traffic management policies on the Hajj transport system. This study is focused on the use of simulation to test the impact of extending the shuttle bus service to hole Nafrah network, and determining the management policies than can achieve the best possible performance of the system. No such work has been carried out.

Chapter 3

Conceptual Model

3.1 Introduction

In this chapter, the conceptual model for the shuttle bus transport system experienced in 1416H to move the Turkish pilgrims along road number nine, is presented. This model is described in the next section. Section 3.3 presents the bus management at Arafat. Section 3.4 presents the road traffic modeling. Section 3.5 presents the bus management at Muzdalifah. Section 3.6 defines the performance measures of the model.

3.2 Conceptual Model

The conceptual model is developed to represent the flow of shuttle buses between Arafat and Muzdalifah. The shuttling buses are responsible of transporting all the pilgrims from Arafat to Muzdalifah. All the buses are under the control of ministry of Hajj and the service organization (Moesssasat Attwafah). The pilgrims are located at Arafat according to the ministry of Hajj plan. Enough space is assigned outside legal boundaries of Arafat to be used as a center and store for the buses. Bus stops (with suitable gates) are constructed on the roads' shoulders, at Arafat and Muzdalifah.

The conceptual model is a traffic model that represents the flow of buses shuttling between Arafat and Muzdalifah. It contains the main elements shown in figure 3.1

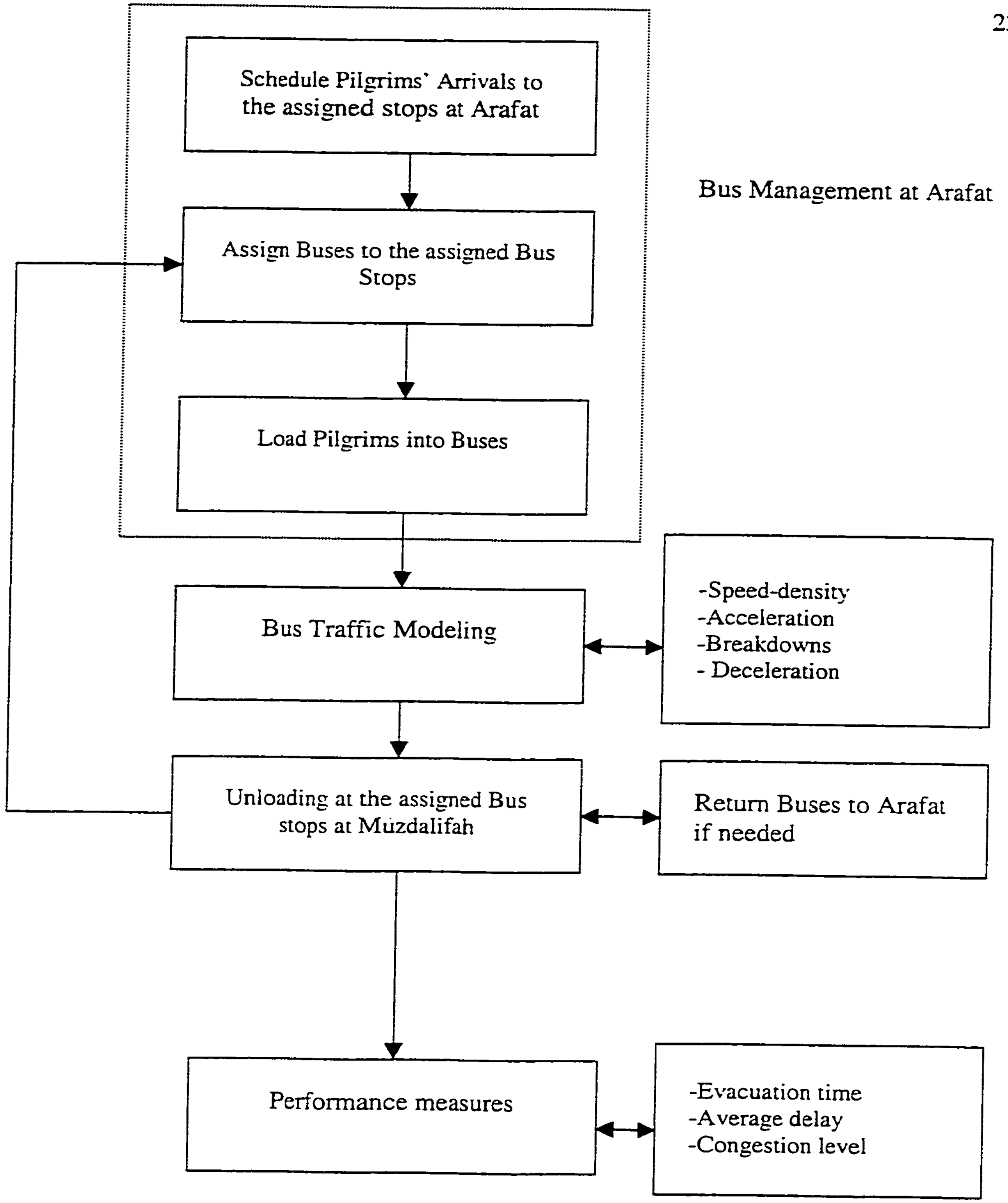

Figure 3. 1 The conceptual model

The main elements of this model are

1. Bus management in Arafat
2. Road traffic modeling
3. Bus management in Muzdalifah.
4. Performance measures.

The details of theses elements are presented in the following subsections.

3.3 Bus management in Arafat

The buses are assigned service offices. Each service office is assigned three bus stops. The buses are parked in a main parking store area, near the road nine, at Arafat. The buses are assigned to the different offices before the start of Nafrah and they are released to the bus stops in successive batches. The number of buses in each batch is equal to the number of bus stops. The pilgrims are moved to the bus stops in groups each of fifty pilgrims is assigned one bus stop and loaded into the bus occupying that stop . When the Nafrah starts the first group of buses departs Arafat taking pilgrims towards Muzdalifah and the following group is released to the bus stops. If a bus arrives at a bus stop while the previous bus is still loading , then it has to wait on the road shoulder until the stop gets free. A fleet of suitable size is kept in the main store to be used in need .

3.4 Road traffic modeling

Upon arriving the road, buses traffic follow the traffic flow laws. They are assigned an operating speed, as a maximum speed that must not be exceeded. Their speed changes according to the density speed relation that will be presented later in section 4.3. Around the bus stop area, buses decelerate and slow down. On the main road, however, they can accelerate whenever the traffic density is low.

Bus breakdown may happen at any point of time based on bus usage. The time between downtime occurrences is assumed follow an exponential distribution . The bus downtime is supposed to follow a uniform distribution. Buses that are broke are assumed not to block the traffic.

3.5 Bus Management in Muzdalifah

Arriving at Muzdalifah, buses can assigned the stops according to two different policies. In the first policy buses have to unload pilgrims at specific bus stops based on Arafat stop from which buses are coming. In this manner a bus can select any of three assigned bus stops. In the second a bus driver has the freedom to select the first available bus stops to unload pilgrims.

3.6 Performance measures

Three important performance measures that can be used to assess any different alternative plans for Nafrah transport system are evacuation time, average travel time, congestion level. The evacuation time, which is defined as elapsed time between start of Nafrah and the time by which the last pilgrim reaches Muzdalifah. This measure will reflect the success in evacuating the pilgrims in the required time.

The average travel time is an important measure since we are concerned about pilgrims' arrival to Muzdalifah in the required time, in addition to pilgrims comfort. The more time they spend in the bus the more difficult for them. The average travel time affects the transport rate, and in turns, it indicates the quality of service provided by the transport system in terms of productivity.

Congestion level or the traffic density is also of great importance when dealing with Nafrah transport system. It influences the average delay, which is a common quantitative measure that captures the essence of service in congested flow situations.

3.7 Conclusion

A conceptual model has been developed for the shuttle bus traffic during Nafrah. The model represents the main elements of this important problem. Next this model will be transformed into a simulation model using Promodel simulator.

Chapter 4

Simulation Model Development

4.1 Introduction

The purpose of this chapter is to present the development of the conceptual model into a simulation model. Available data from the shuttle previous experiments is used and several assumptions are also made to develop the simulation model. The chapter is organized as follows: the details of the steps followed to develop the simulation model are given in section 4.2. The density-speed relation assumed for the road traffic is presented in section 4.3. Section 4.4 identifies the data required to use the model. Section 4.5 describes the verification and validation approaches used for the model. The important results for road nine are presented in section 4.6. finally section 4.7 concludes the chapter.

4.2 Simulation Model

The conceptual model depicted in Figure 3.1 is developed into a simulation model using the following steps

1. Specifying model assumptions
2. Adopting practical operational strategies based on previous experience with shuttle bus system in Hajj
3. Utilizing the appropriate features of ProModel to represent traffic Modeling

Each of these steps is described next.

4.2.1 Assumptions

- All pilgrims are assumed to be available at Arafat when the simulation starts.
- All buses are ready to move when simulation starts.
- The shuttle bus system is used only.
- The exiting road network is used.
- All the roads are flat and smooth.
- Each road is assumed to have two lanes, each lane has some bus stops in Arafat and Muzdalifah.
- Each bus is assumed to be 12 meters long, 2.75 meters wide, and with 50 passengers occupancy.
- The inter-arrival of bus break down follow an exponential distribution.
- The downtime of the buses follow a uniform distribution.

4.2.2 Shuttle Bus Operational Strategy in 1416H

The simulation model is basically based on the shuttle bus operational strategy experienced in 1416 H. The steps followed in that year are summarized below

- At 18:15 was the start of preparing the buses in the main store for Nafrah, according to the service offices.
- At 18:30 the first three batches were released. In this step a total number of 69 buses, assigned to 23 offices moved to Arafat.
- At 18:45 the start of loading the pilgrims on buses.
- At 18:55 the start of Nafrah from Arafat to Muzdalifah. (The Nafrah was delayed for few minutes due the pedestrians' movement on the shuttle bus path at Arafat.
- At 19:10 release of more batches towards Arafat.

- At 00:45 the end of Nafrah.

4.2.3 ProModel Important Features

Road nine is represented in *ProModel* as a set of path segments and nodes. Path segments and nodes are used to make up a particular path network. Each path segment is assigned a distance in order to measure the vehicles travel time on the path network. Path nodes mark the end points of the path segments. They also mark the points along a path network where resources (buses) can interface with a location. Nodes are also used to control the bus traffic through the use of node logic or search routines such as work and park searches. Path nodes have a limit on the number of resources in route to the node, this determines the road capacity. Multiple segments may share the same path node to represent intersections. Sometimes it may even be desirable to break a long path into several path segments to station buses, or to control their movement better.

In order to represent the road capacity each lane is broken into several subsections. The node limits for each subsection is used to define the capacity of that subsection.

Service offices and bus stops are represented as locations and assigned capacities that determine the number of pilgrims that the location can hold at any one time. Pilgrims arriving at each service office are routed to three bus stops. Bus sops are located on both sides of the road connected to the road nodes via interface elements.

Buses are modeled as dynamic resources. In ProModel dynamic resources are elements that move along an assigned path network. Dynamic resources may escort or transport entities between locations, such as a bus moving pilgrims from Arafat to Muzdalifah. They may also need to process entities at several locations, such as an operator performing tasks at more than one location. The resource will appear during the simulation run traveling along the path network. Resources are created using *ProModel* Resource Module, which consists of an edit table for creating resources and a Resource Graphics Window for selecting graphics to represent the resources. Some of the important fields of the edit table are described below.

Name this selects the name for identifying the resource (helps in assigning different buses to different location, and different routes.).

Units this field determine the number of units of this resource. Any numeric expression may be entered for the number of units and this expression is evaluated only once prior to processing any initialization logic.

Resource Usage Downtime Editor

This is used to define the distribution for the resource 'time to failure.

Resource Specifications dialog box, which is used to define any optional movement for the resource (buses), contains information for defining the operating characteristics of each resource (bus) in the system. The Resource Specifications dialog box includes the path network, name of the home node which is the node where the resource is positioned at the beginning of the simulation, speed, acceleration, deceleration, pickup time (seconds), and deposit time (seconds).

Node logic consists of resource statements executed when a resource enters or leaves a path network node. Node logic may be defined for any dynamic resource at any node. Typical uses of node logic are controlling traffic and gathering special statistics on resource movement.

4.3 Traffic Modeling

A linear speed- density relationship is assumed to simplify its consideration in time model. As given in May [23] the equation for this relation is

$$u = u_f - \left(\frac{u_f}{k_f}\right)k$$

Where u is speed, u_f is free flow speed (maximum speed), k is density, k_f is jam density.

This relation indicates that speed reaches free flow speed when density (and flow) approaches zero. As density (and flow) increases, speeds are reduced until flow is maximum, and speed and density approach their optimum values. Further increase in density result in lower speed (and flow) until density reach its maximum value and corresponding speed (and flow) approaches zero.

This relation is written as a subroutine in the buses' speed field. The parameters are updated at the entry /exit node logic of each lane section to adjust the buses' speed accordingly.

4.4 Data Required to Use the Model

1. Pilgrims data, which includes
    a. Total number of pilgrims.
    b. Distribution of pilgrims to camps in Arafat.
2. Road network data. It includes
    a. Number of roads and length of each road.
    b. Number of lanes in each road.

c. Traffic plan that includes the road assignment to different nationalities.

3. Space available in Arafat and Muzdalifah. This includes

   a. Maps of the area of Arafat, Muzdalifah, and road network.

   b. Camps allocation in Arafat.

   c. Space available for bus stops.

   d. Space available for parking.

4. Buses data

   a. Number of buses available.

   b. Lengths and sizes of buses used.

   c. Buses breakdown including time and duration of breakdown.

   d. Bus loading and unloading time.

   e. Maximum allowed speed.

4.5 Model verification and validation

Verification is the process of determining that a simulation computer program performs as intended, i.e. verification checks the translation of the conceptual simulation model into a correctly working program. The developed model has been verified using three approaches. In the first approach the buses are assigned constant speeds. The time taken by a bus to traverse the distance between Arafat and Muzdalifah is checked and found to agree with the laws of motion. In the second approach, the ProModel interactive debugger is used to trace the simulation states to find programming errors. Also dynamic plots for the traffic density, speeds, and traffic volume were constructed during the simulation run-time. In the third approach the animation of both bus traffic and output statistics is observed. This animation reflected a reasonable performance of the simulation model.

Validation is concerned with determining whether the conceptual simulation model (as opposed to the computer program) is an accurate representation of the actual system. A simulation model is said to be valid if it reproduces with enough accuracy the behavior of the real system.

Generally there are two types of validation: conceptual validation and operational validation. The conceptual validation is performed prior the beginning of coding, to ensure that the model's assumptions are correct, complete, and consistent. The role of operational validation is to check whether the model's output data closely resemble the output data that would be observed from the real system.

Prior to the verification and validation steps, an experiment is conducted to determine the number of replications required to run the model. The experiment is based on the evacuation time as the main performance measure calculated by the model. The model is run using 400 replications. A 90 % confidence interval on the evacuation time is constructed. When 500 replications are used, an average evacuation time of 5.729 hours is found to be inside the confidence interval constructed when 400 replications are used. Therefore, the utilization of the model is based on the 400 replications.

The first validation step was concerned with testing whether the simulation model has the ability to reproduce the density speed relation. In this step eight scenarios were developed to control the density of one selected lane section. In each scenario, the traffic density of the selected lane section was maintained at fixed level. The space mean speeds resulting from the different scenarios were plotted versus the different traffic density levels. The plot indicated the ability of the model to generate the speed density relation found in the existing traffic theory. The density speed fundamental diagram generated by the model is shown in Figure 4.1.

In the second validation step the model is ran using 400 replications. This resulted in average travel time of 20.131 minutes (with a standard deviation of 1.0423 minutes). The result indicated only 3.23 % deviation of the simulated average travel time from the observed one (1416H average travel time). The average simulated evacuation time was 5.719766 hours (with a standard deviation of 0 .16 hrs.) with 0.98% deviation from the observed one.

4.6 Results for Road 9

In this section we present the experiments conducted using the traffic simulation model to study the effect of the number of bus stops, bus stops spacing, the number of buses used, bus management, and buses' breakdown on the performance of the shuttle bus transport system. The experiments are carried out for specific ranges for the values of both the number of bus stops and the bus stops spacing. These ranges are determined by the spatial constraints. The length of the bus stop is determined according to the standards of the transportation-planning handbook, Edwards [16]. Section 4.5.1 describes the results of the study carried out using the simulation model developed for road nine to investigate the effect of bus stops number and spacing. Section 4.5.2 presents the effect of the bus fleet size.

4.6.1 The number of Bus Stops and Bus Stops Spacing

This section presents the study of the effect of the number of bus stops and the bus stops spacing on the Nafrah evacuation time and average travel time. The number of bus stops

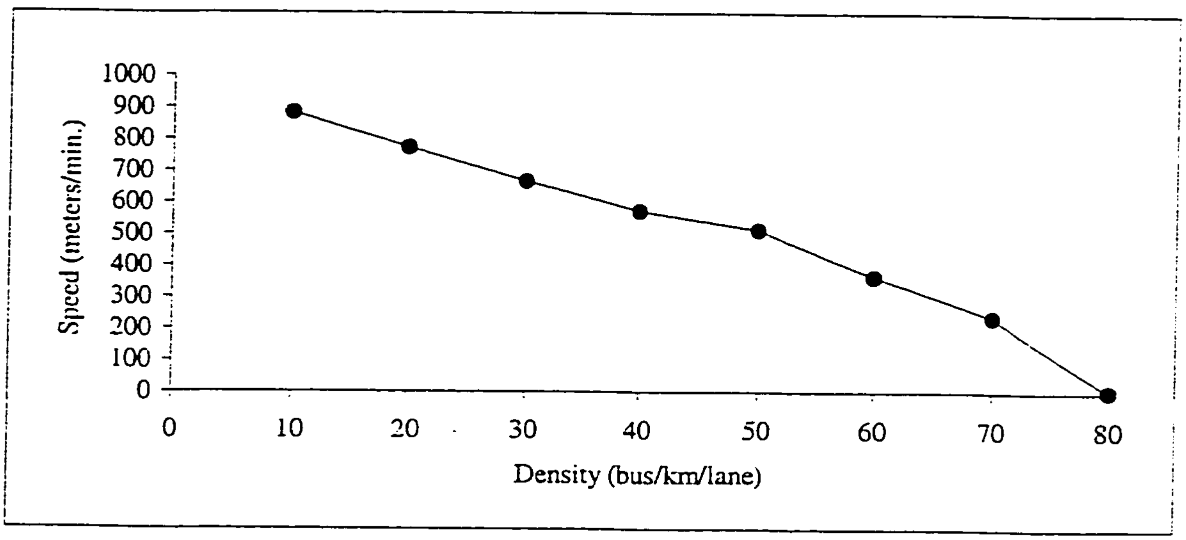

Figure 4.1 Density-Speed relation as generated by the model

Table 4.1 Simulated and observed results.

Parameter	Observed	Simulated	% Deviation
Average travel time	20.1	20.75	3.23
Evacuation time	5.683	5.719	0.98
Average system time	-	3.16	-
Average waiting time	-	2.65	-

Table 4.2 Confidence interval on the average travel time and evacuation time

Parameter	Mean	L90%C.I.	H90%C.I	Std.
Average travel time	20.1	20.04	20.216	1.127948
Evacuation time Hrs.	5.719	5.68	5.75	0 .16

is influenced by several factors, such as the space availability for the stops, road capacity, service demand (total number of trips required), the average travel time, time headway, and the time spent at the bus stops. The spacing of the bus stops on the other hand, influences the traffic density and road bus spacing, and in turn these two influence the bus speed and time spent at the bus stops area. Minimum space must be available between bus stops so that drivers can control their vehicles better and have more maneuvering freedom. Wider spacing allows higher speeds and low density, and hence short travel times. But as the spacing increases the number of stops decreases. This results in lower traffic flow and in turn lower transport rate.

The goal should be to minimize the trade-off between the pilgrims' average travel time and the amount of time they spend waiting at the bus stops area (average waiting time).

As a first step, upper and lower limits on the required number of bus stops can be developed as follows:

The release rate of the buses, R can be estimated by the formula

$$R = \frac{N}{D} \qquad 4.1$$

Where

N =the number of bus stops

D =time delay at the bus stops

If we assume that the going lane reaches the steady state jam traffic density, K_j, in an interval of time equals to the average travel time T_1, then

$$RT_1 \leq K_j \qquad 4.2$$

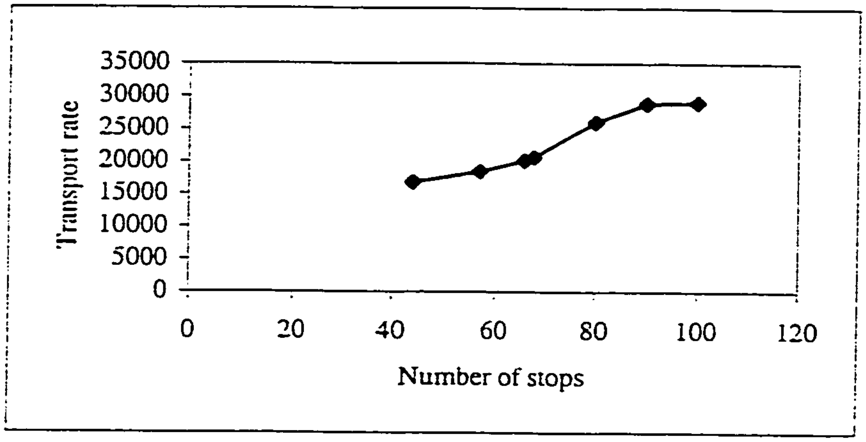

Figure 4.2 The relation b/w the number of bus stops and the transport rate

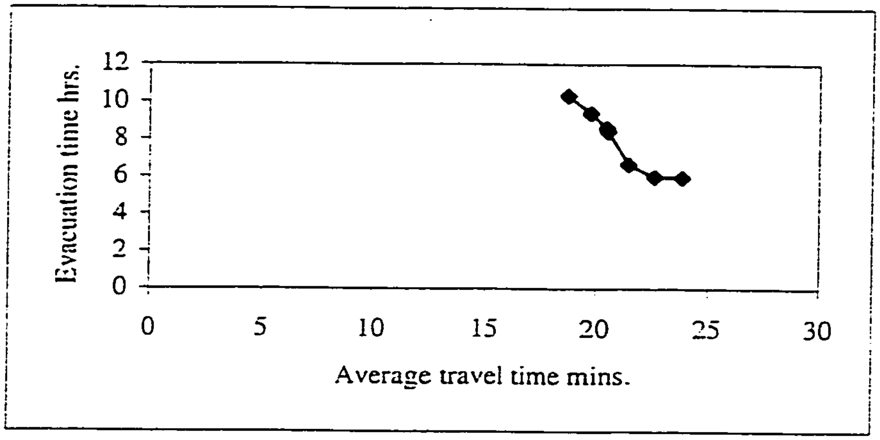

Figure 4.3 The relation b/w the average travel time and the evacuation time

And if we assume that the system is operating with its optimum density Ko, and optimum travel time, T_o (i.e. under the maximum traffic flow conditions), then

$$K_o \leq RT_o \qquad 4.3$$

Equations 4.2, and 4.3 define the upper and lower limits on the required number of bus stops respectively.

Since the average road length is about 10 km, hence each km can accommodate about 80 buses moving with average travel time, which we assume to be of 20 minutes, 4.2 gives

$$N = \frac{800}{20} \times 4 = 160$$

The available space for on street stops at Arafat and Muzdalifah is always less than this value, which may be considered as the upper limit.

As a second step, several experiments are conducted using shuttle bus traffic model developed for road nine, to evaluate the effect of changing the number of bus stops, and bus stop spacing on the performance measures.

Starting with the number of bus stops used in 1416H, we first test the effect of reducing the number of bus stops keeping the number of pilgrims fixed. This is done in four experiments. In each experiment a total number of 117000 pilgrims are transported, one or more of the bus stops is removed, the stop spacing is recalculated, and the pilgrims are evenly distributed among the remaining bus stops. Table 4.3 shows the effect of reducing the number of bus stops on the average travel time and evacuation time.

It can be observed that as the number of bus stops decreases the average travel time decreases, but the evacuation time increases. The decrease in the average travel time is

Table 4.3 The effect of the number of bus stops on the system performance measures when .117000 pilgrims were transported via road 9.

Number of bus stops	Average travel time in minutes	Evacuation time in hours	Hourly transport rate
68	20.53	5.68	20599
66	20.47	5.81	20138
57	19.77	6.34	18454
44	18.78	6.97	16786

due to the low density and consequently high speeds. The increase in the evacuation time can be contributed to the low hourly traffic volume and transport rate.

Next the effect of increasing the number of bus stops is studied. We used three different scenario based on the number of bus stops. Each time we add more bus stops and adjust the bus stops spacing accordingly. Since our goal is to increase the transport rate, we don't redistribute (as we did previously) the pilgrims; instead we assign new groups of pilgrims to be transported through the new bus stops. Doing this, we will increase the total number of transported pilgrims, while searching for the best value of the number of bus stops. In the first scenario we use 80 bus stops to transport a total number of 136000 pilgrims. If we assume that the length of the bus stop is 20 meters (the standard is 20 meters plus one bus length[16]), the corresponding spacing is 30 meters. Running the simulation model for these settings results in 21.43 minutes average travel time, 5.23 hours evacuation time, and 26003 pilgrims per hour transport rate. In the second scenario, 90 bus stops are used where the corresponding spacing distance is about 24 meters and a total number of 153000 are transported. Third scenario uses 100 bus stops and 20 meters spacing distance. The results of running these scenarios are shown in Tables 4.4,4.5, and 4.6

4.6.2 The fleet size

The optimal bus fleet size can be estimated as the number of buses occupying the stops and the number of buses those are running on the road under the maximum traffic flow conditions. If the fleet size is less than the optimal size the average waiting time will increase and consequently the evacuation time will increase. The evacuation time can be estimated as follows

Table 4.4 The effect of the number of bus stops on the system performance measures when the number of pilgrims is changed.

Number of bus stops	Average travel time in minutes	Number of pilgrims	Evacuation time in hours	Hourly transport rate
80	21.43	136000	5.23	26003
90	22.61	153000	5.30	28877
100	23.84	170000	5.85	29060

Table 4.5 the effect of number of bus stops on the performance measures when 136000 pilgrims were transported

Number of bus stops	Average travel time in minutes	Number of pilgrims	Evacuation time in hours	Hourly transport rate
80	21.43	136000	5.23	26003
90	22.71	136000	4.86	27983
100	23.46	136000	4.65	29247

Table 4.6 The effect of fleet size on the evacuation time and transport rate when 90 bus stops are used

Number of buses	Number of pilgrims	Evacuation time in hours	Hourly transport rate
400	153000	5.88	26020
450	153000	5.43	28177
490	153000	5.30	28868
500	153000	5.30	28868

$$\text{Evacuation time} = \frac{TP}{C \times N} \tag{4.4}$$

And

$$N = nb\left(\frac{60}{T}\right) \tag{4.5}$$

From 4.4 and 4.5 we get

$$\text{Evacuation time} \approx \frac{TP}{nb\left(\frac{60}{T}\right)C} \tag{4.6}$$

Where

N= the number of trips per hour.

C= capacity of the bus

TP= total number of pilgrims

T =average trip time.

nb =the number of buses used.

To find the best fleet size we start with a smaller size to run the simulation model and observe the resulting values of the performance measures. Then we increment the fleet size with a suitable step and run the model. We continue incrementing the fleet size until we observe that no gain can be obtained from adding more buses to the fleet. We perform this process using three different values for the number of bus stops, namely 80, 90, and 100 bus stops.

These results show that, if the fleet size is small to the extent that the time lag for buses arriving from Muzdalifah, is large, then time headways at the bus stops will increase(as shown in Figures 4.2 and 4.3.) and the pilgrim's average waiting time will also increase. This has a direct impact on the evacuation time.

4.6.3 The effect of bus management

The way in which buses are assigned to bus stops at Arafat and Muzdalifah has a clear impact on the performance measures. The current bus management system assigns different buses to different service offices. This practice reduces driver's freedom to select the closest stop and hence may result in higher evacuation time. To test the effect the bus management we compare the current practice with the situation where buses are not assigned to specific stops, instead each bus can select the first available bus stop. Simulating the latter scheme resulted in 5.09 hours evacuation time vs. 5.67 hours for the former. But it may more difficult to use the free selection scheme. Figure 4.4 shows the effect of the current bus management system on the traffic density at Arafat area. Figure 4.5 shows the effect of the free selection scheme on the traffic density at Arafat area.

4.6.4 The breakdowns

Since the buses breakdown data is not available, we assume that the breakdowns inter-arrival times follow exponential distribution and the downtimes follow uniform distribution. To test the effect of the bus breakdown we run the model assuming mean time to failure to be 4 hours and mean downtime to be 30 minutes. The results show that the Nafrah is delayed about 28 minutes.

4.6.5 Recommendations for Road 9

The results from the previous section indicate that this road, if used as an exclusive 2-lane bus way will be capable of transporting 173250 pilgrims in 5.97 hours, using 470 buses.

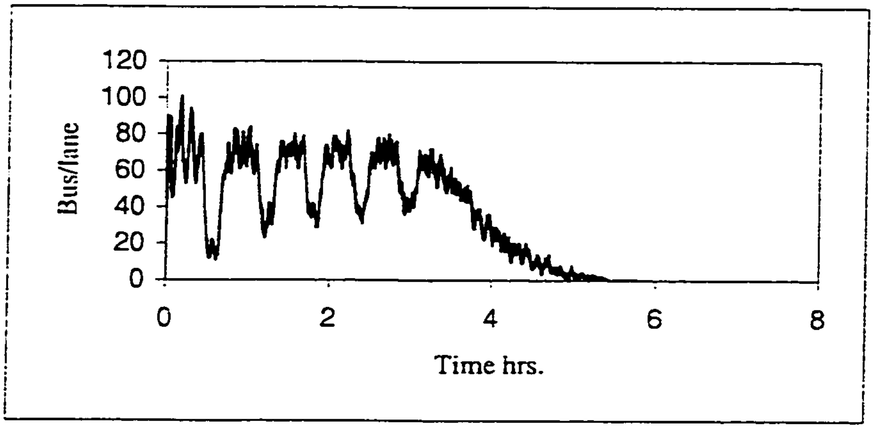

Figure 4.4 The traffic density at Arafat when 400 buses are used

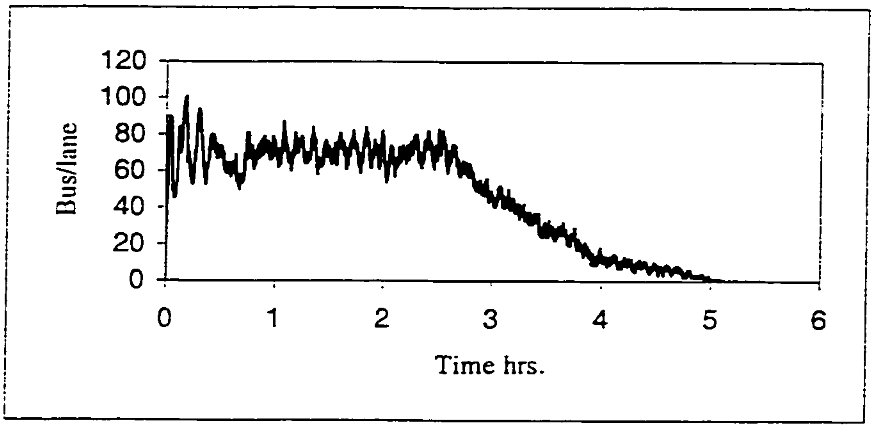

Figure 4.5 The traffic density at Arafat when 470 buses are used

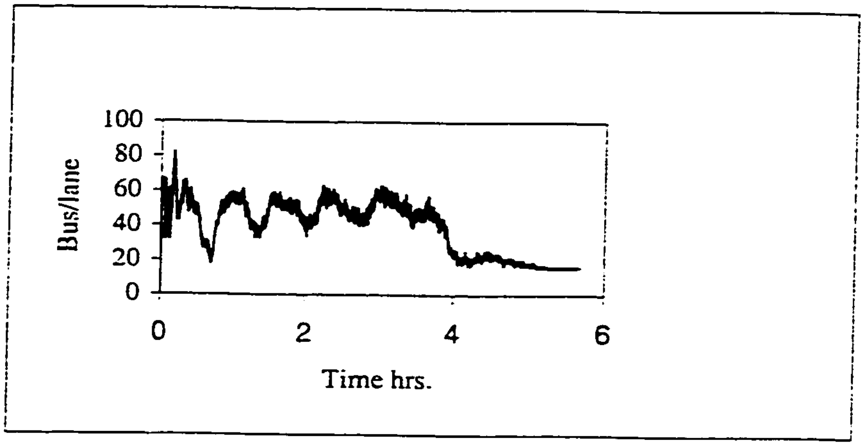

Figure 4.6 The effect of restricted bus management on the traffic density at the bus stops area

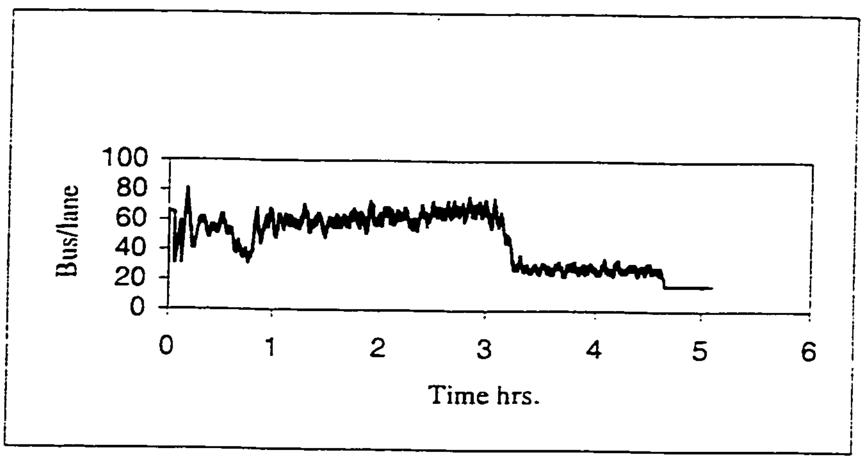

Figure 4.7 The effect of free selection bus management on the traffic density at the bus stops area

400 replications are used to construct 90% confidence interval on the evacuation time. The resulting confidence interval is (5.9489, 5.9831). Therefore it is recommended to use 470 buses and 100 bus stops.

4.7 Conclusion

The development of the conceptual model into a simulation model has been presented. We specified model assumptions, adopted practical operational strategies based on previous experience with shuttle bus system, and utilized the appropriate features of ProModel. We used data from 1416H shuttle bus experiment on Road nine to validate and verify the model. Then we used the model to determine the number of bus stops, bus stops spacing, and the fleet size that can achieve best values for the performance measures.

Chapter 5

Comprehensive Model for Nafrah

5.1 Introduction

This chapter presents the application of the developed traffic simulation model to test the impact of allocating the remaining Nafrah highways to the shuttle bus service. The results obtained for road nine are useful since most of the roads are similar. The number of bus stops at Arafat and Muzdalifah are determined based on the available space for each road. Section 5.2 presents the detailed resulted for these roads and selects the number of buses can be used to achieve best values for the performance measures. Section 5.3 is intended to balance the traffic on the different Nafrah highways. Section 5.4 gives the recommendations and concluding remarks.

5.2 Results of the model

The results for road 9 are presented in the previous chapter. The developed simulation model is also used to determine the number of bus stops, bus stops spacing, and fleet size for roads 8 through 2. Experiments similar to those of road 9, are conducted. For each road, we change the number of bus stops, and the fleet size and then run the simulation until the best number of bus stops and fleet size are found The detailed results of these experiments are presented in this section.

5.2.1 Road 8

Currently, this highway is used to transport a total number of 90,000 Iranian pilgrims. It is possible to locate 100 bus stops at Arafat and 90 stops at Muzdalifah for this road. If we use 81 bus stops at Arafat and Muzdalifah we can transport about 155,250 pilgrims in 5.88 hours. The fleet size to achieve this task is 370 buses. The corresponding travel time is about 22.5 minutes. The detailed results for different fleet sizes used are summarized in table 5.1

5.2.2 Road 7

This road and road 6 are used to transport a total number of 260,000 pilgrims from the Arabic countries. Using 81 bus stops at Arafat and Muzdalifah, 148500 pilgrims can be transported in 5.6 hours. The average travel time is 21.68 minutes. A fleet size of 360 buses is required to achieve this. When 90 bus stops are used a total number of 166750 pilgrims can be transported in 5.93 hours using 390.

5.2.3 Road 6

The results of this road are similar to those of road 7. A total number of 166750 pilgrims can be transported in 5.93 hours when 90 bus stops are used at each of Arafat and Muzdalifah. The required fleet size is 390 buses.

5.2.4 Road 5

150,000 pilgrims can be moved via 90 bus stops at Arafat and 80 bus stops at Muzdalifah using 350 buses in 5.92 hours. The average travel time is 20.08 minutes. Different values for the evacuation time and hourly transport rate corresponding to different fleet sizes for this road are given in table 5.4.

Table 5.1 the effect of fleet size on the Nafrah evacuation time and transport rate along road 8

Number of bus stops	Fleet size	Number of pilgrims	Evacuation time in hours	Hourly transport rate
80	300	155250	6.38	24334
80	330	155250	6.13	25328
80	370	155250	5.88	26040
80	380	155250	5.88	26040

Table 5.2 the effect of fleet size on the Nafrah evacuation time and transport rate along road 7

Number of bus stops	Fleet size	Number of pilgrims	Evacuation time in hours	Hourly transport rate
81	420	148500	5.94	25000
81	400	148500	5.94	25000
81	370	148500	5.94	25000
81	360	148500	5.94	25000
81	350	148500	6.00	24750

Table 5.3 the effect of fleet size on the Nafrah evacuation time and transport rate along road 6

Number of bus stops	Fleet size	Number of pilgrims	Evacuation time in hours	Hourly transport rate
90	350	166750	6.09	27381
90	370	166750	5.99	27838
90	390	166750	5.93	28119
90	400	166750	5.93	28119

Table 5.4 the effect of fleet size on the Nafrah evacuation time and transport rate along road 5

Number of bus stops	Fleet size	Number of pilgrims	Evacuation time in hours	Hourly transport rate
90	490	150000	5.92	25337
90	450	150000	5.92	25337
90	400	150000	5.92	25337
90	390	150000	5.99	25041
90	370	150000	5.88	25510
90	350	150000	5.85	25641

5.2.5 Roads 3 and 4

These two roads are similar and each road can accommodate 100 bus stops at Arafat and 92 bus stops at Muzdalifah. In such situation a total number of 184800 pilgrims can be transported in 6 hours using a fleets size of 450 buses. The average travel time is 21.28 minutes.

5.2.6 Road 2

The available space for stops at Arafat can accommodate up to 90 bus stops for this highway, however, only 45 bus stops can be allocated. In such case 140000 pilgrims can be transported in 5.95 hours using 290 buses.

5.3 Balancing the Traffic

To balance the traffic on the different Nafrah highways foreign pilgrims can be reassigned to these highways using the results of section 5.2. Table 5.8 shows one possible traffic balancing solution assuming 1420H pilgrims ' camp allocation plan.

5.4 Conclusion

The developed simulation model is used to study the effect of extending the shuttle bus service to the whole Nafrah highways. The number of bus stops and bus stops spacing is determined for each highway. The traffic is balanced on the different roads according to the capacities and camps' allocation .

Table 5.5 the effect of fleet size on the Nafrah evacuation time and transport rate along roads 3 and 4

Number of bus stops	Fleet size	Number of pilgrims	Evacuation time in hours	Hourly transport rate
100	500	184800	5.93	31163
100	490	184800	5.93	31163
100	430	184800	5.96	31006
100	400	184800	5.98	30903
100	450	184800	6.20	29806

Table 5.6 the effect of fleet size on the Nafrah evacuation time and transport rate along road 2

Number of bus stops	Fleet size	Number of pilgrims	Evacuation time in hours	Hourly transport rate
80	250	140000	6.33	22116
80	270	140000	6.13	22838
80	290	140000	5.95	25044
80	300	140000	5.95	25044

Table 5.7 The results for Nafrah comprehensive model

No.	Number of pilgrims	Number of stops	Fleet size	Evacuation time(hrs)	Average travel time (min)
9	173,250	100	470	5.97	23.46
8	155,250	81	370	5.88	22.5
7/6	166,750	90	390	5.93	21.68
5	150000	90	350	5.92	20.08
4/3	184800	100	450	6.00	21.28
2	140000	90	290	5.95	21.11
Total	1.321,600	741	3160	-	-

Table 5.8 Traffic balancing on the different roads

No.	Capacity	Assignment		Evacuation time(hrs.)
9	173,000	140.000	33.000	5.97
		Turkish	S. E. Asia	
8	155,000	90,000	65.000	5.88
		Iranian	S. E. Asia	
7	166,000	152,000	14.000	5.93
		S. E. Asia	Arabs	
6	166.000	166.000		5.93
		Arabs		
5	150.000	80.000	70.000	5.92
		Arabs	S. Asia	
4	184,000	184,000		6.00
		S. Asia		
3	184,000	46,000	138.000	6.00
		S. Asia	Free	
2	140,000	90,000	50.000	5.95
		Africans	Free	

Chapter 6

Conclusion

6.1 Summary

The objective of this research is to develop a traffic simulation model that can help in planning and traffic management during Nafrah period. Basically the shuttle bus transport system experienced on Nafrah road number 9 is modeled.

The Nafrah transportation problem was stated in chapter 2. In this chapter, also, the literature in Hajj transportation problem and traffic simulation models was reviewed and the basic traffic stream parameters were studied. The conceptual model developed for the shuttle bus traffic was presented in chapter 3. Chapter 4 focused on the simulation model development. In this chapter the necessary model assumptions were presented, practical operational strategies based on previous experience with shuttle bus system was adopted, and the appropriate features of ProModel utilized to construct the simulation model were described. The details of road traffic modeling and model verification and validation are also given in this chapter. Followed by the experiments conducted to test the effect of number of bus stops, bus stop spacing, and fleet size on the Nafrah performance measures, and results and recommendations for the case of road number 9. Chapter 5 contains the comprehensive Nafrah traffic model, where the shuttle bus transport system was extended to serve the other eight roads previously served by the conventional Hajj transport system. The best value for the number of bus stops, and fleet size was determined for each of these roads. A traffic-balancing plan was suggested in this chapter to distribute the pilgrims among the different roads, taking into account the camps' allocating at Arafat.

6.2 Future Research

The simulation model in this study can be extended in many directions. These directions include the following

1. The same model can be tested using other type of traffic equations that relates speed, density, etc.
2. The same model can be extended to include different modes of transportation on the same road network.
3. The model can be tested when realistic data becomes available about the buses breakdown.
4. The model can be extended to include the traffic between Muzdalifah and Mina.
5. The model can be extended to other areas in Hajj transportation.
6. Effort should be made to collect data that is relevant to simulation. This data will help in any future studies using simulation.

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