A system of mobile service units for the large-scale event industry: an implementation for the Hajj, the pilgrimage to Makkah, Saudi Arabia

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A SYSTEM OF MOBILE SERVICE UNITS FOR
THE LARGE-SCALE EVENT INDUSTRY
An Implementation For The Hajj, the Pilgrimage to
Makkah, Saudi Arabia

FADEL M. Y. OTHMAN

PhD thesis submitted at Wolfson School of Mechanical and Manufacturing Engineering, Loughborough University, UK.

November 2003
In the Name of Allah, the compassionate, the Merciful,

Praise be to Allah, the Lord of the Universe,

and Peace and Prayers be upon His Final Prophet and Messenger.

To those who are proud to be the servants of the pilgrims to Makkah; I dedicate this work.

Fadel Othman
ABSTRACT

The success of the large-scale event industry, which deals with managing events such as Olympiads and occasional mass tourism, depends mainly on two factors: the quality of the program, and the quality of the facilities and services provided. The mega-event of the Hajj, the annual Muslim pilgrimage to Makkah, Saudi Arabia, currently attracts more than two million visitors from all over the world for about two weeks; generating a huge demand for services, for short periods, at four nearby pilgrimage cities. Therefore, in order to enhance the feasibility, availability, and the quality of services for the Hajj of the future, a system of Mobile Service Units (MSUs) is proposed, instead of fixed service centres, to serve the expected 4.8 million pilgrims by year 2025.

A Multi-disciplinary engineering approach has been used to investigate the proposed system of Mobile Service Units in macroscopic and microscopic scales on the light of the new master plan for the cities of the Hajj. A survey (questionnaire) was conducted to investigate the opinions of service providers (297 respondents) to be considered. Various designs and configurations were developed to investigate the ability to construct the proposed system. Modelling and simulation of the system were used to develop and to investigate the operation and the control for the system and its effect on the mass transportation of pilgrims during the Hajj.

It is found that whilst the service providers consider the current services relatively sufficient, they are enthusiastic regarding implementing the proposed Mobile Service Units for the Hajj of the future. They contributed actively in determining 44 types of services that they considered as feasible to be mobile and highlighted their concerns, which are resolved by the findings of this research and the master plan for the cities of the Hajj.

The possibility of making the proposed system of MSUs has been confirmed from many perspectives. The web search has revealed that many mobile services are available commercially and special MSUs could be built using existing technology. More MSUs designs and configurations are proposed and various urban design layouts have demonstrated their integration with the master plan of the cities of the Hajj. Moreover, an abundant and low-cost resource for making MSUs is identified by recycling out-of-service buses used for the Hajj, and modular extension units are proposed to simplify converting these buses to spacious MSUs. Simulation results have identified the proper service capacities for the proposed MSUs.

An approach for Just-In-Time MSUs (JIT-MSUs) is shown, by simulation, as feasible to control the proposed system of MSUs, through an online control of the orders to move MSUs to provide the right services, at the right place, at the right time; achieving higher efficiency and utilization of resources. A Fuzzy Logic method is used, on a microscopic scale to issue requests for MSUs according to local situations; and on a macroscopic scale to evaluate all requests according to global conditions relating to the system as a whole. Simulation results confirm that MSUs will not affect the mass transportation of pilgrims as they make use of the unused capacity of the Shuttle Buses road networks. Simulation results also show that a significant reduction in resources, and a high increase in profit, compared with fixed services can be achieved using the proposed MSUs.

It is concluded that, the proposed system of MSUs is technically, operationally and economically viable and expected to contribute to the success of the mega-event of the Hajj throughout providing an adequate amount of a wide variety of quality facilities and services, at all locations, whenever needed, without increasing the cost of services. Further studies for establishing the proposed system of MSUs for the Hajj and integrating it with the Shuttle Buses transportation system, according to the master plan of the cities of the Hajj, are suggested.
نظام وحدات خدمات متصلة لصناعة المناسبات الكبيرة

واستخدامه في الحج

ملخص أطروحة الدكتوراة لفايفه محمد محمس في الهندسة الميكانيكية

إن صناعة المناسبات الكبيرة، والتي تتميز بإدارة المناسبات مثل الدورات الأولمبية والسياحة المقولة ذات الضرور الجماهيري الكبيرة، يعد جناها بصورة أساسية على عاملين آتى: جودة البرنامج وجودة المراكز والخدمات المقدمة. هذا ويعتبر الحج مناسبة كبيرة جدا تستقبل حاليا أكثر من مليوني زائر سنويا من جميع أنحاء العالم لمدة أسبوعين تقريبا، مما يؤدي إلى إنتاج كبير في جسم الطلب على الخدمات، لفترات قصيرة، في كلما من المراكز المقدمة ومكة المكرمة. وللخروج أبعاد خدمات الحج ويواجه تحديات موجودة مستقبلية، فمن المفترض استخدام نظام وحدات خدمات متصلة بدلاً من الخدمات الثابتة لخدمة حوالي 4,8 مليون حاج متوافق وصولهم بعد عام 1445 هـ (2024 م).

لقد استخدم منهج هندسي متحدث التخصصان لدراسة النظام المتصل للجهاز المثير للإعجاب، وتطويع تصاميم ومخططات متصلة لإمكانية تنفيذ النظام، وبناء نموذج حاسوبي وإجراء عمليات محاكاة بالحاسب الآلي لتطوير ودراسة أسلوب إدارة النظام والتحقيق فيه تأثيره على حركة التشغيل الكمية في الحج.

لقد وجد أنه في حين يعتبر مقدما الخدمات مسند توفر الخدمات الحالية للحج كافية نسبيا، فإنهم متحسسون بالنسبة للتطبيق نظام الخدمات المتصلة للحج متصل قليلا. كما شارك مقدما الخدمات بنضجها في تحديد 44 نوع من الخدمات التي أعتبرها مجدية لتكون متصلة، ووضوح عمالة متصلة ينبغي مراحتها. وفجأة أمكن ملاحظة تلك العوامل من خلال نتائج هذه الدورة والمخطط الشامل للمتطلبات المقدمة.

لقد تبين إمكانية إنشاء النظام المتصل من خلال عدة محاور. حيث تبين النتائج البحث عبر الإنترنت وجود أوجه متصلة من الخدمات المتصلة في السوق العالمية وأن وحدات الخدمات المتصلة ذات التسويات الخاصة يمكن تنفيذها في التقنية الحالية. كما أقترحت الدراسة عدة تصاميم ومخططات إضافية للخدمات المتصلة ولكن عرضة لنتظرية كافية لتثبيت الخدمات المقدمة. إضافة إلى ذلك فقد تم التعرض على مصدر وآخر منصات المتصلة ليتها خدمات المتصلة من خلال إعادة تأهيل الحافلات الحج التي تخرج من الخدمات، واقتراح وحدات مصغرة تغيير الحافلات إلى وحدات خدمات متصلة فضية. مما بات نتائج المحاكاة بالحاسب الآلي لعرض الخدمات المتصلة لوحدات الخدمات المتصلة المفترضة.

لقد بنت نتائج البحث جداول أسلوبا متصلة لتوفر الخدمات المتصلة في الوقت المناسب تم تطويره للتحكم في النظام المتصل، من خلال إعداد تطوير أدوات لوحدات الخدمات المتصلة لتوفر الخدمات المطلوبة، في المكان الصحيح، في الوقت المناسب، لتحقيق كفاءة أعلى واستهلاك أقل للموارد. وقد استخدمت إدارات مكتبة آلاف الموارد. وقد أظهرت الأدوات إعداد تكامل الخدمات المتصلة (شيئياً) في كل من بيانات طلب وحدات الخدمات المتصلة بناء على الظروف المحلية لكل موقع، وعلى المستوى العام لتقديم جميع الطوابع العامة للمشترع المأمون بالموضوع. كما أظهرت الأدوات نتائج النظام قبلاً لحوكمة نقل الحافلات الكبيرة حيث يستخدم نظام النقل الكبيرة على شبكة مواصلات إلكترونية متصلة. كما بدت نتائج المحاكاة أن فيها كبرى التأثيرات وزيادة كبرى في العوائد الاقتصادية يمكن تحقيقها من خلال استخدام نظام وحدات الخدمات المتصلة مباشرة وبناء الخدمات الثابتة.  

ويخلص البحث إلى أن نظام وحدات الخدمات المتصلة المفترض يمكن تنفيذه من الناحية التقنية والتشغيلية والتكنولوجية، ومن المتوقع أن يصبح في تنازل للحج، من خلال توفير قدر كافى من نوع متصل متصلة من الخدمات والمراكز الجديدة، في جميع المناطق، حسب الحاجة إليها، بدون زيادة تكلفة الخدمات. ويقترح البحث اعتماداً على الدراسات لتفتيح النظام المتصل وكفاءة نظم التوقيت بالحافلات الرفدية وفقاً للمخطط الشامل للمتطلبات المقدمة.
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GLOSSARY

Al-Mashaeer: The pilgrimage cities of Arafat, Muzdalifah and Mina, near Makkah city, western part of Saudi Arabia.

Almsjed Al-Haram: the Grand Mosque of Makkah

AWT: Average Working Time

CTHMIHR: The Custodian of the Two Holy Mosques Institute for Hajj Research, Umm Al-Qura University, Makkah, Saudi Arabia.

customer.hr: A unit used in this research to measure the amount of service provided through time. This unit is analogous to the unit of (man.hr) commonly used in industry.

ERSBS: Exclusive Roads for Shuttle Buses Service.


EWT: Equal Working Time = Sum of duration of all jobs / total MSUs

fuzzy inference: is a method that interprets the values in the input vector, based on some set of rules, and assigns values to the output vector.

GIS: Geographical Information Systems.

GPS: Global Positioning Systems.

HFS: Hajj Facilities Services.

inhabitant.hr: A unit used in this research to measure the amount of available service capacity provided through time.

IT: Information technology.

JIT MSUs: Just-In-Time MSUs (JIT MSUs) is an approach suggested by this research through active online control of the movements of MSUs to provide services just in time wherever needed.

KBS: Knowledge Based Systems.

Membership function (MF): is a curve that defines how each point in the input space is mapped to a membership value (or degree of membership) between 0 and 1.

MFs: Membership Function/s for fuzzy controller

MSU: Mobile Service Units.
MSU, MSUs: Mobile Service Unit, Mobile Service Units

Mutawifteen: Service establishments for the pilgrims.

Overshoot: The maximum amount by which the response overshoots the steady-state value. It is often used as a measure of the relative stability of a control system, a system with a large overshoot being usually unstable.

Pilgrim Unit (PU): A unit introduced to simplify simulation, presentation of data and can be used for managerial purposes.

1 PU = 50 pilgrims = the average capacity of a large bus

Pilgrimage areas/cities: The Holy places of Makkah, Mina, Muzdalifah, and Arafat in the western part of Saudi Arabia.

Service capacity for an MSU: The amount of population that an MSU can be assigned to serve. Its unit is (inhabitant).

Service status: The difference between the total capacity of a service (provided by MSUs and fixed services) and the demand for service. Its unit (inhabitant) or (PU).

Serving job: A job for a particular MSU to provide service at a particular zone for a specified duration of time.

Tawaeef services: Special types of services provided for the pilgrims.

The Control Centre: A centre located in a support zone of the master plan and issues serving jobs orders to MSUs operators.

The Hajj: The annual Islamic pilgrimage to Makkah and the Holy Places, Saudi Arabia.

The Umrah season: The season of mass visitors to “Almsjed Al-Haram” to perform “Umrah”, especially during the month of Ramadan.

Total over-supply: The surplus of services provided over a period of time measured in the unit of (inhabitant.hr)

Total under-supply: The shortage of services provided over a period of time measured in the unit of (inhabitant.hr)

TWT: Total Working Time for an MSU for all jobs

unstable orders: any tow contradicting orders to MSUs of the same group serving at a particular zone within a predefined period.

Zone: One of the zones of the new master plan for the cities of the Hajj. Each zone accommodates 200,000 pilgrims,

Zone-123: Zone - City Number - Loop Number - Zone order in the loop
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CHAPTER ONE
A Background for the Research

1.1 An Overview of Chapter One

This chapter aims to give the reader a background to this research by briefly describing the event industry and its importance, the mega-event of the Hajj, the importance of services for the Hajj, a background to the project in developing transportation services for the Hajj, the difficulties associated with providing fixed services for such a mega-event and the proposed system of Mobile Service Units (MSUs) to overcome these difficulties.

The contents of Chapter One are organized as follows:

1.1 An Overview of Chapter One 1-1
1.2 The Large-Scale Event Industry 1-2
1.3 The Hajj as a Mega-Event 1-3
1.4 The importance of services for the Hajj 1-5
1.5 Project's background in developing transportation services for the Hajj 1-6
1.6 Project's background in developing services for the Hajj: the proposed system of Mobile Service Units (MSU) 1-11
1.7 Closure 1-14
1.2 The Large-Scale Event Industry

The large-scale event industry deals with large events such as Olympiads, football finals, world fairs and exhibitions, and occasional mass tourism.

An event is something of importance that is pre-planned to occur at a specific time and place. It is an activity that occurs outside the regular routine of an organisation, can take a variety of forms and can be of international or local importance. A mega-event is an event that attracts an extra-ordinary number of national and international visitors, and it involves several venues, facilities and services, as well as attracting extensive media coverage. Mega-events have clear impacts (economical, sociological, and environmental) on the host organisation and community, and requires extensive planning and organising. (Barhamain, 1997)

The event industry is an ever growing and profitable business. For example, it is estimated that Britain earns somewhere around £200 million per annum from overseas visitors attending different events (Seeking, 1996). Moreover, Mega-events yield a substantial economical benefit to the host destinations. Mihalik (1994) wrote that Atlanta’s 1996 Summer Olympic Games generated $2 billion in construction projects in Georgia, including sports, education and housing facilities. In particular, the games were a catalyst for achieving a $42 million federal housing grant to revitalise a low-income housing estate next to the Olympic village.

The event industry has clear economic roles such as marketing, image making, and as catalyst for the host community’s improvement (Gets, 1997). Events are particularly important to the tourism and hospitality industry because it motivates travel, and acts as a tourist attraction (Pyo, 1995).

An event must be manageable and controllable. The major components and/or elements of the event industry that are (mostly) under control are: 1) The event’s program (i.e. theme, objectives, etc.), which represents the main component of any event; 2) The facilities and services available within the event’s venue. These elements are the determiners of an event’s success (Saleh and Ryan, 1993;
Oppermann, 1996). Barhamain (1997) findings supported this argument in general and confirmed that each component/element affects the other. The event’s programme is affected by the facilities and services available (e.g. the venue’s capacity might affect the event’s programme), and the programme can also affect the types of the required facilities and services.

1.3 The Hajj as a Mega-Event

The Hajj; the annual Muslim pilgrimage to Makkah and the Holy Places, Saudi Arabia, is a Mega-scale event, that currently attracts more than two million visitors from all over the world, for about two weeks, by the end of the Islamic lunar year, spending a few days in each of the nearby four pilgrimage cities of Makkah, Arafat, Muzdalifah and Mina (Figures 1.1 and 1.2). The Hajj is of a great importance to more than one billion people over the world because it is the fifth pillar of Islam. Pilgrimage is obligatory, just once in a lifetime, only for those who are physically and financially able to perform it.

The Mega-event of the Hajj attracts more international visitors than any other event, for example, the Hajj 2000 attracted 10 times more international visitors than Sydney 2000 Olympiad (PriceWaterhouse, 2001, reported that Sydney Olympiad attracted more than 110,000 Games-time specific international visitors). Therefore, it is no wonder that the Hajj is described as the biggest annual mass movement of people on the plant (BBC, 2002). Moreover, the Hajj will continue to attract more visitors in the future (Figure 1.3), as the Master plan for the cities of the Hajj (Beeah, 1999), predicts that 4.8 million visitors/pilgrims will perform the Hajj by year 2025.

The Hajj event has a well-defined programme. It is performed within various venues and involves different types of facilities and services. The Hajj is widely covered by national and international media and provides a unique opportunity for those of different nations to meet one another. Although the Hajj is a religious event and not for profit, it has great economic impacts on the private and governmental sectors in Saudi Arabia, and other international travelling companies benefit from such an event (Barhamain, 1997).
Figure 1.1: Pilgrims stay few days in each of the four nearby pilgrimage cities while performing the Hajj (An aerial photo of the four cities of the Hajj)

Figure 1.2: The Hajj is a Mega-event that currently attracts more than two million pilgrims from all over the world for about two weeks. (A photo for the northern part of Muzdalifah)
Figure 1.3: Extrapolation of the expected number of Pilgrims until year 2025
(Source: Beeah 1999)

1.4 The importance of services for the Hajj

Barhamain (1997) showed that beside the programme quality, the success of a mega-event depends mainly on: 1) the availability, 2) accessibility, 3) affordability, and 4) presentability of facilities and services. In other words, during a mega-event the facilities and services needed must be available within the venue involved, reachable and easy to find, inexpensive to use, and well presented and delivered by the people involved. Because the Hajj programme is prescribed, he argued that the success of such a mega-event depends upon, and should be related to, the success of preparing, managing, and providing the required facilities and services to the participants. He also indicated that, concerning large-scale events, both physical (i.e. hardware, buildings, infrastructures, etc.) and non-physical aspects (i.e. software, social interactions, service quality, management, etc.) of facilities are important.

The type of services needed for pilgrims are mainly food, drink, health care, information, security, safety, transportation, accommodation, emergency, administration, communication, toilets, ablution, etc.

The customers' satisfaction issue is important in the service industry because the main goal of the service provider is to have a satisfied customer. Barhamain (1997) measured the participants' attitude concerning the facilities and services provided, and his results indicate that:
1) The pilgrims feel that the present Hajj Facilities and Services (HFS) available within the Hajj venues are satisfactory, however, they believe that such facilities and services could be improved;

2) The pilgrims agree to an improvement of HFS but are not willing to pay extra money for better HFS. In other words, the results suggest that pilgrims want better HFS but do not want to pay extra money for them. The only way he suggests to solve this dilemma and provide better and affordable facilities and services, is through improving the quality and/or the provision of the facilities and services available (i.e. by effective management), and such a process does not necessarily require extra costs.

He also found that most of the pilgrims in the sample were of a comparatively low income. This result was anticipated since many of Muslim Countries have a very low national income. His result suggests that the HFS must be provided with reasonable prices and a higher value.

1.5 Project's background in developing transportation service for the Hajj

The researcher has experienced the Hajj many times. During the Hajj 1990, while stuck in a traffic jam for few hours, a solution to prevent traffic jams and improve the transportation system in the Hajj was sought as part of a personal interest. It was understood that such a crowd is expected when huge number of people gather in a limited area and use a large number of buses and vehicles for transportation, but there must be room for further developments.

The problem of traffic jams during the Hajj can be related to the use of a huge number of vehicles for transporting about 2 million pilgrims, within a short time period, to the same place, through limited road networks (Figure 1.4). Due to the limitation of space in the pilgrimage areas, it is difficult to extend road networks since it will be at the expense of the areas most needed for the pilgrims. On the other hand, it is impractical to limit the number of pilgrims to fit the capacity of
transportation system. Therefore, the possibility to reduce the number of vehicles and increase their efficiency was investigated.

Two papers were published (Othman, 1991/1 and Othman, 1991/2), in which two concepts were proposed to improve transportation and other services for the Hajj. The first proposal was suggested in order to solve the problem of traffic jams, long travel time, air pollution, and to increase the efficiency and economy of transportation (Othman, 1991/1). It proposed a system of transportation using shuttle bus service, private bus stops, and exclusive bus road, or "Exclusive Roads for Shuttle Buses Service" (ERSBS). The concept depends mainly on four principles:

1) To increase the number of passengers and to reduce the number of vehicles; only "Big Buses" will be used for shuttle bus service. No private or small buses will be used;

2) To ensure smooth traffic flow and eliminate traffic congestions, shuttle buses will use "Exclusive Roads" assigned for it;

3) To eliminate the need for parking spaces for private buses, and prevent pilgrims from getting lost, "Private Bus Stops" will be assigned for each group of pilgrims near their campus in the four-pilgrimage areas. Shuttle bus service will operate between these bus stops for each group individually.
4) To save the valuable space inside pilgrimage areas, “Main Bus Service Parking” will be located outside pilgrimage areas somewhere between Arafat and Muzdalifah.

Figure 1.5 shows these principles applied to the “Establishment of Turkish, European, American, and Middle-Asian Pilgrims”, an establishment responsible for Hajj arrangements for more than 130,000 pilgrims at that time.

![Figure 1.5: The Main Components of the ERSBS Transportation System](image)

The new ERSBS transportation system was established through successive stages: In the Hajj 1995, The Custodian of the Two Holy Mosques Institute for Hajj Research (CTHMIHR) conducted a large-scale study, which demonstrated the possibility of implementing the proposed system and specified the requirements for a large-scale experimental operation to prove the concept (CTHMIHR-1, 1996). Due to the sensitivity of the Hajj and the importance of performing a successful pilgrimage season, a huge debate and detailed discussions took place before the experiment was finally approved (CTHMIHR-2, 1996). Great support was given to the experiment by the Governor of Makkah region, the Ministry of Transportation, and the CTHMIHR Institute.

In the Hajj 1996, a limited ERSBS experiment was conducted from Arafat to Muzdalifah. Civil work modifications such as: separating the road and constructing bus stops and service parking, were conducted by the Ministry of Transportation.
Staff from the CTHMIHR and Umm Al-Qura university, were deeply involved in training programs, conducting the experiment, and supporting the staff of the governmental bodies and the transportation company. In that experiment, more than 117,000 pilgrims were successfully transported from Arafat to Muzdalifah within 5 hours using 520 buses (instead of 1270 buses in the old system). The travel time was reduced from 224 to 20 minutes (CTHMIHR, 1997). The results of that experiment proved the validity and the benefits of the new transportation system, and encouraged the governmental bodies to extend its implementation.

In the Hajj 1997 the system was again successfully implemented, but this time run completely by the employees of the governmental bodies and the transportation company. The experiment was also extended to cover the transportation link from Muzdalifah to Mina. In the Hajj 1998, all transportation companies were involved in the operation of the ERSBS system to extend the operational experience and spread the awareness of the benefits of the system. In the Hajj 1999, the transportation system was extended to cover the complete journey. In the Hajj 2000, the system continued to operate successfully with some changes in administrative structure. Afterwards, the system of transportation became a standard for the Establishment.

The system of ERSBS established itself as the most efficient transportation system for the Hajj. This is due to the remarkable results of implementing the system in the past few years. Generally speaking some of these results (Othman, 1998) include:

- Transporting more than 140,000 pilgrims successfully from Arafat to Muzdalifah (about 9 km), within 6 hours time span (from sunset to midnight).
- Reducing the transportation time from Arafat to Muzdalifah and from Muzdalifah to Mina by up to 91%. This made total saving of more than (880,000 man.hour) of transportation time for the pilgrims of the Establishment.
- Reducing the number of buses needed for transportation by up to 62 %, which represents a saving of nearly £2.3 million every Hajj.
- Increasing the transportation capacity by 205%.
• Achieving the capacity of (28,400 passengers/hr), which is comparable to the capacity of a light train (31,000 passengers/hr - Beeah 1998).

• Reduction in fuel consumption by 80%.

• Converting more than 60,000 m² of car parking to valuable areas for pilgrims in Muzdalifah (Figure 1.2).

• Providing a better and safer environment for the pilgrims by the separation between pedestrians and vehicles (Figures 1.2 and 1.5).

• Providing fast emergency services.

• Providing improved food services.

The success of the ERSBS system of transportation encouraged the government (Ministry of Transportation) to introduce a new master plan for Almashaer (Beeah, 1999). Figure 1.6 shows the new master plan, which consists of six major bus freeways. Each freeway serves four zones in each of the pilgrimage areas of Arafat, Muzdalifah and Mina. The master plan is made to accommodate the expected number of 4.8 million pilgrims by the year 2025.

The master plan is the outcome of a series of consultations, coordination and technical meetings with many governmental bodies working in the Hajj, conducted by the Beeah consultants from 1997 to 1999. The master plan covers the general strategies for road networks, land use, transportation, accommodation, services, infrastructure, utilities and implementation stages. The master plan studied various transportation systems, and recommended using buses as the main transportation system for the Hajj.
1.6 Project’s background in developing services for the Hajj: the proposed system of Mobile Service Units (MSU)

The current practice for providing services for the two million pilgrims in Arafat, Muzdalifah, and Mina depends mainly on fixed service centres provided in temporary bases. Most services in Makkah are permanent but need to be increased in number and capacity during the Hajj through temporary bases as well. The problem is that if fixed service centres are continuing to be provided for the expected number of 4.8 million pilgrims by the year 2025, they have to be repeated in the four areas, making the total service capacity enough to serve 19.2 million pilgrims while only serving 4.8 million at any time (Figure 1.7). The short stay of pilgrims in these places according to the Hajj program, which are uninhabited for the rest of the year, for only a few days makes providing these fixed services economically unsound. As a result, it discourages private sector investments, and increases the load on governmental sectors, which currently heavily subsidize most services for the Hajj.
Figure 1.7: Repeating fixed service centers at the four pilgrimage cities dublicates resources

The second proposal (Othman, 1991/2) was a concept for providing better and more affordable services in the four pilgrimage areas (Makkah, Arafat, Muzdalifah, and Mina), by allowing for the movement of these services from one area to another, instead of providing repeated fixed services everywhere. This concept will be developed and investigated as the theme of this research work.

In order to enhance the feasibility, availability, and the quality of services for the Hajj, the development of a system of Mobile Service Units (MSUs) is suggested, which can be transported from one place to another before and after the movement of pilgrims/visitors (Figure 1.8).
These MSUs will be parked in service parking near pilgrim camps (Figure 1.9). Pilgrims will walk from their camps to the nearest MSU parking to get the service (food, health care, information, security, etc.) they need, or to their dedicated bus stop to take a bus to the next pilgrimage area. Pedestrian walkways networks allow them to move freely to other MSUs parking for more services. The movement of MSUs will be scheduled/managed in such a way that it satisfies the need for services in the different areas without affecting the movement of pilgrims. This can be done by proper scheduling/management of the movement of MSU to avoid peak times of bus movement during the Hajj, especially during the mass movement of pilgrims from Arafat to Muzdalifah to Mina in day 9 and 10 of the month of the Hajj. The proposed system of MSUs will be developed and investigated based on the guidelines of the master plan for the cities of the Hajj.
1.7 Closure

The importance of the large-scale event industry was briefly addressed and the annual international mega-scale event of the Hajj was briefly described. The importance of services for the success of the large events in general and the Hajj in particular was demonstrated. The background of developing one of the most important services for the Hajj, i.e. transportation services, by developing the ERSBS transportation system was giving and its successful results were briefly described. The system of Mobile Service Units (MSUs) for the Hajj, which is proposed to eliminate the need to repeat fixed services every where and to improve the quality and the cost of services provided; was roughly described and the intention of this research work to take the concept further, based on the master plan for the cities of the Hajj, was highlighted.
CHAPTER TWO

Literature Review and the Outline of the Research

2.1 An Overview of Chapter Two

This chapter reviews the literature on topics related to the proposed research work then describes briefly the research work and its outline. The contents of Chapter Two are arranged as follows:

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2.2 The Literature Review

The proposed system of MSUs is multidisciplinary in nature and can be viewed, developed and investigated from different angles. Therefore, a macroscopic-scale review of the literature is needed to look over the different aspects related to the proposed system. The literature review is grouped under the following headings for simplification:

2.2.1 Mega events; planning and impacts

Getz (1989) mentioned that special events are a unique form of tourism products, but they should not be viewed narrowly as mere attractions for exploitation in tourism development schemes. He argued that effective event planning and management must be based on a comprehensive model. Conclusions were drawn concerning potentially useful research themes for increasing our understanding of events and improving events tourism planning. This highlights the importance of making a comprehensive model for the Hajj in the current research.

Bojanic (1993) investigated the effect of both strategic and environmental factors (such as quarterly attendance, new attractions, world crisis, etc.) on the tourist area life cycle for Cypress Gardens (a plants, habitats and recreational attraction). He hypothesized that both types of factors can have a revitalization effect on the tourist area life cycle. A step-logarithmic function was used to model the attendance for the tourist attraction. Strategic and environmental factors were both found to have a significant effect on the life cycle and the step-logarithmic function demonstrates a very good model fit for the life cycle. This highlights the importance of recognizing internal and external events that affect the life cycle of a tourism attraction and assessing their impact on the attendance or visitation.

Roche (1994) argued that the search for explanation should guide mega-event research. The influence of planning, political, and urban contextual processes and factors on mega-event production was illustrated through a discussion of comparative event research and a case study of Sheffield's Universiade 1991. His
research indicated the important influence of contextual societal change, urban leadership, and nonrational planning in event production processes. These factors were important for understanding both event causation and also the potentially rational character of event policymaking.

Hawkins (1994) mentioned that in September 1991, the World Travel & Tourism Council (WTTC), a global coalition of chief executives from all sectors of the travel and tourism industry, has established the World Travel & Tourism Environment Research Centre (WTTERC). The centre aimed to bring together the elements needed to provide good environmental practice in the travel and tourism industry and to provide a catalyst for responsible tourism policies. This highlights the international concerns on good environmental practice in the travel and tourism industry, which need to be considered in this research.

Shortt (1994) mentioned that much of the attitudinal research in tourism has concentrated on tourists and host communities, while the attitudes of professionals concerned with planning for tourism have been overlooked in the research on attitudes to tourism and its development. He examined the attitudes of tourism planners in Australia, hypothesizing that those responsible for the planning of tourism are at the centre of impact assessment. He presented some exploratory findings in relation to the attitude systems of a number of subgroups concerned with planning in Australia and, having identified some contradictions in attitudes towards tourism, presented some recommendations for human resource development. The current research took such view in consideration and investigated the opinions and the concerns of service providers for the Hajj.

Hiller (1995) mentioned that conventions represent a special form of tourism with a high degree of ecological differentiation from the host society. The encapsulation of conventioneers in highly planned convention activity creates an intrusion-reaction response from the host city - particularly when the convention reaches a size threshold that makes it a mega-event. In place of the intrusion-reaction model, he proposed an interactive-opportunity model using case studies. A sociological perspective demonstrates how interaction benefits (rather than merely economic benefits) can transform the convention-host city relationship. The current research
needs to consider such interaction benefits while developing the proposed system of MSUs for the benefits of the hosting cities.

Bramwell (1997) examined strategic planning in Sheffield, England, around its hosting of the 1991 World Student Games, considering this before and after the mega-event. Aspects of strategic planning considered in his case study were identified from three theoretical perspectives on strategy: the classical, processual and systemic. His paper focused on three aspects of Sheffield's strategic planning around the 1991 Games. The first aspect is the extent to which strategic planning was effective in linking the Games investment with the development of tourism for urban regeneration. The second is the degree to which there was a clear strategy around the Games investment both in advance of, and following, the Games. The third aspect is whether strategy emerged from formal analysis and decision-making or by learning, accident and political processes. The social and political circumstances affecting Sheffield's planning are also central to this assessment of strategy. The lessons from Sheffield's strategic planning include that research and monitoring are needed before and after a mega-event, a mega-event should be integrated with broad development planning, and the importance of a long-term perspective on mega-events.

Smith (2003) mentioned that in 1998, the Canadian Tourism Commission has released vision and mission statements for the tourism industry. He described the process by which the vision and missions statements were created, as well as the historical context that lead to an environment in which such statements were deemed needed. In particular, the history and evolution of a national tourism marketing organization is reviewed as well as the emergence of a strong voice for industry in the operations of a national tourism marketing body. The general process used for creating the vision and missions statements can be adapted for this research.

2.2.2 Services for the Hajj

Al Rahman (1988) examined the influence of the Haram (Sanctuary) on the Land Use pattern in Makkah, a city that serves two populations of land user, both residents and pilgrims. On examination, the institution of Hajj (pilgrimage) proved to be the major mechanism generating the power of the Haram; this in turn created an ever-
rising need for a whole range of services, most especially accommodation and the supporting infrastructure. Moreover, the Haram itself has affected the Land Use pattern and exerted a pull effect on the pattern of Land Use, Value, Tenure and satisfaction of the tenants and operation of land users. He provided a backcloth description of the city of Makkah at present, and examined the evolution of the Land Use pattern. Then he assessed the current influence of the Hajj on Land Use, investigated the influence of the Haram on the horizontal plane and on the vertical dimension, and evaluated the impact of regulatory measures on the Land Use pattern. These factors encourage the current research for applying the proposed system of MSUs, to give great flexibility for providing services according to the changing Land Use pattern.

Mekki (1988) investigated, from the geographer's viewpoint, the problems of urban transportation in Makkah outside the period of Hajj. He showed the significant ways in which different modern methods of transportation has affected population mobility and discussed the role of public transport in the city. He examined specific problems resulting from the rapid increase in the number of private vehicles on the city's roads (mainly traffic jams and long travel times), and showed different aspects of the effects of the rapid increase in the number of private vehicles and the expansion of the city.

Al-Harigi (1989) examined the relationship between the Prophet's Mosque in Al-Medina and its surrounding physical environment, the effect of these changes on the spirituality of the city and the public perception of change. This highlights the importance of putting in consideration the spirituality dimension by the current research.

Al-Abdaly (1990) proposed a solution for some urban problems (such as inadequate infrastructure facilities and traffic congestion, etc) for the city of Makkah after considering some basic issues such as land and property boundaries and the complexities of land ownership. He carried out three types of opinion survey among the pilgrims, landowners and other professionals of related fields. He gave priority to vital issues mainly connected with the pilgrimage, such as the enlargement of the praying areas, provision of suitable accommodation and other facilities. The current
research will focus on provision of mobile services and facilities for the pilgrims (not including accommodation).

Al-Rakeiba (1991) discussed and analysed the most important factors affecting the transport of pilgrims, such as transport facilities and increased numbers of pilgrims. He determined and evaluated the breakdown of the movement patterns according to the Hajj objective and pilgrimage instructions, then identified and discussed the major transport problems which pilgrims face in the Hajj region, and made some suggestions for their solution.

Alghamdi (1993) investigated the real dimension of thermal discomfort experienced inside the pilgrimage tents. Data, including climatic measurements taken inside the tents, was collected from the field investigations during the Hajj season of 1989. The investigations also included a subjective evaluation for internal thermal conditions by the pilgrims from Europe, the Middle East, and South East Asia. He also attempted to identify passive and natural cooling guidelines that were applicable to the tent's design. He measured the thermal effects of some of the natural cooling techniques on pilgrimage tents at Makkah. His research concluded with design guidelines to improve the thermal quality of the pilgrimage tent. The recommended guidelines were based on the experimental results and practical examples of cooling strategies applied to tents in similar hot climates. These guidelines help to design MSUs for better thermal comfort.

Al-Ken (1995) investigated the work of the Saudi Arabian media and the information services in relation to the Hajj. He examined the policies, procedures and problems faced by them, and proposed solutions and improvements to serve more effectively the needs of the pilgrims, with their different cultures and languages. He also included the daily routine of the average pilgrim during the 1993 Hajj season, the various sources of information, the Saudi Arabian official Hajj policy and procedures, the ministries and committees administering the Hajj and their terms of reference, and specific problems related to weather, transport, accommodation, food, health, and security. His work helps for better designs for MSUs offering information and public awareness services.
Ismail (1996) measured expectations of customer service and perceptions in the Pilgrims Management and Fund Board in Malaysia. The data collection strategy used was that of the triangulation method. The findings from structured questionnaires were supplemented by interviews where possible and selected observation of operations. The structured questionnaire was statistically analysed by the SPSS computer program. Gaps were detected between customers' expectation and employees' perception of that expectation (Gap A), between customers' and employees' perception of the service delivery process during and after transaction (Gaps A & B), and between customers' expectation and their overall perception of customer service delivery. Parameters, which gave rise to customers' expectation, were further explored. Gender, age, marital status, educational level, income, media exposure and a monopoly supplier situation were found not to have a significant correlation with expectation. Dwelling area was significantly correlated but in the opposite way to the expected; the less sophisticated rural dwellers had higher expectations. Personality was inversely related; weaker personalities had higher expectations. Only 2 out of 17 values were significantly correlated to customer expectation; mature love and self-respect. His work helps for better understanding of customers' expectations and achieving their satisfactions.

Barhamain (1997) explored the importance of the facilities and services required within venues for large-scale events with respect to the actual users' perceptions. A typical mega-event (the Hajj) was explored. A quantitative research approach was employed to collect and analyse the research data, and an exclusive tool (i.e. a questionnaire) to measure the participants' perceptions concerning the importance of facilities and services was constructed. From the results, five indices were developed to comprise the various aspects and types of facilities and services required within the different Hajj venues. It was found that the types of facilities and services required in a particular venue correlate to the programme taking place in that venue. It was revealed that security and safety are perceived by participants as being a highly important factor required during mega-events. Other facilities and services were also of concern to participants. It was concluded that both physical (e.g. buildings), and non physical aspects of facilities and services (e.g. appropriate treatment of participants), and the interactions between them, were important and
ought to be considered in further research, as well as in the practices of the large-scale event industry. Six factors were found to have a clear and dominant effect on the participants' perceptions regarding the importance of facilities and services. The factors concern: 1) nationality, 2) verbal communication, 3) participants' age, travelling experience, 4) training, 5) orientation, and 6) resident and non-resident of the host country. The proposition concerning the two determinants of an event's success was supported by the research's findings, and it was argued that beside the programme quality, the success of a mega-event depends mainly on the availability, accessibility, affordability, and presentability of facilities and services. His work highlights many aspects for this research and determines the important factors for the success of a mega-event that need to be considered by the current research.

Al-Harrbi (1998) analysed the results of pilgrims' satisfaction with all aspects of their existing accommodation as a micro built environment, as well as with their neighbourhood and the city of al-Madina as a macro level of the built environment. At the accommodation level, the analysis involved testing the pilgrims satisfaction with their accommodation in relation to their satisfaction with its location and accessibility, its exterior and internal characteristics, its environmental conditions, its infrastructure and services, its socio-cultural environment, its economic condition and its aesthetic value. At the neighbourhood level, the analysis contained the pilgrims satisfaction with the neighbourhood location and accessibility, its internal characteristics, its roads and pedestrian walkways, its public facilities and services, its socio-cultural environment and its aesthetic values. At the city level the analysis included the pilgrims satisfaction with the Prophet's City's accessibility, its internal characteristics, al-Haram, the city roads and pedestrian walkways, the public facilities and services, the socio-cultural environment, the aesthetic values and general satisfaction with the Prophet's City. His procedure can be used for measuring pilgrims' satisfaction regarding the facilities and services provided by the proposed system of MSUs.

Badabaan (2000) described, explained and predicted the travel behaviour of different groups of pilgrims during the Hajj period. He focused on identifying the association between pilgrims' characteristics and their mode choice between Makkah and the
holy areas (Arafat, Muzdalifah and Mina), as well as analysing pilgrims' modal interdependencies between these different trip legs. In addition, he identified the factors influencing the travel behaviour of pilgrims in relation to mode choice for the trip from Mina to Al-Haram on the 10th, 11th and 12th days of Dhul-Hijjah (the month of the Hajj). Finally, he made forecasts for pilgrims' mode choice behaviour for this trip, for a selected range of hypothetical transport policy scenarios. His work helps for predicting the travel behaviour for pilgrims, which helps in turn for predicting the shift of demand for services from one place to another.

2.2.3 Serving customers and quality assurance

Al-Fattal (1987) dealt with a M/G/1 priority queuing system when all the customers have the same service time distribution. Most of his work was devoted to studying the best dividing point which divides the arrival stream into two priority classes according to the service time required by each customer in order to minimise the overall average time in system. This was done for both the preemptive resume and the nonpreemptive priority disciplines, when the service time distribution and the actual service time for each customer is known beforehand. The relation between the best dividing point and the mean service time and the mean arrival rate has been studied. They suggested a simulation method of estimation under the nonpreemptive priority discipline. On the contrary, if the service time distribution is known and the actual service time for each customer is unknown beforehand, then such a division point is not possible. Here one appropriate discipline is the last-come first-served with service interruption (LCFS/I) discipline, which is related to the priority queuing discipline, because the new arrival has a priority over the customer who is being served. He suggested also another possible procedure which is the first-come first-served with service interruption (FCFS/I) discipline. Finally, They compared all the above-cited priority disciplines to find out which one is the best. His work helps service providers to improve their procedures for providing services at different scenarios.

Mefford, R. (1993) mentioned that as economies of industrialized countries become ever more dominated by services and competition in service businesses increasingly
is global, many service firms are realizing that quality will be the major determinant of their success. Yet producing consistently high quality in services has not received as much attention as in manufacturing firms. Characteristics of services have led many managers to believe that quality improvement methods used successfully in manufacturing are not applicable in service organizations. He argues that this is not true and, in fact, approaches such as just-in-time, total quality management and work teams, suitably adapted, can work also in service firms. The importance of a proper service philosophy and strategy is crucial to establishing high quality and continual improvement in services. How a firm can develop this philosophy and the programs that support it, were discussed with examples of high quality service organizations cited. The current work will investigate the possibility of making use of just-in-time approach for the services provided during the Hajj.

Ho, Lau, and Li (1995) described an appointment-scheduling rule (ASR) to reduce customers waiting time considerably while increasing the facility idle time at a manageable minimum. They evaluated environmental factors that may affect the performance of ASRs, such as the probability of no-shows, the coefficient of variation of service times, and the number of customers per service session, then discusses several exceptional situations such as walk-ins, seasonality of customer arrivals, and multiple-priority/queues. Their work can be used to reduce customers waiting time for MSU services.

Filiatrault, Harvey and Chebat (1996) reported the results of empirical research on service quality and service productivity management practices. The objective of their research was to gain a better understanding of these practices through a comparative analysis of large and small businesses, of firms delivering services to organizations and to consumers, and of unionized and nonunionized firms. A second objective was to correlate these practices to two performance variables: financial results and perceived customer satisfaction. The most frequent practices have been identified. Various quality practices were associated with customer satisfaction but not with financial results. Productivity practices were less popular than quality practices, but some were related to both financial results and customer satisfaction. An important problem was that quality has been defined and redefined in many ways that often
embody elements of productivity. Their work helps service providers to improve both productivity and quality practices for MSUs services for better financial results and customer satisfaction.

Coelho (1996) presented a systematic approach to the analysis of performance (specifically for water supply and distribution), by creating a framework in which a variety of concepts and criteria can be included. His approach was based on the establishment of standardised performance measures, developed as an extension to the existing engineering analysis and modelling procedures. His approach can be used for evaluating the performance of various MSU services.

Ghomi (1997) investigated the contribution that can be made to Quality Management System design and implementation through the application of discrete event simulation methods. A simulation model for Quality Management Systems was defined and its use in a case study was demonstrated and evaluated in detail. The overall result illustrated the feasibility of using computer simulation in the area of quality management and great benefits were achieved.

Field (1998) developed a flexible, portable and predictive model of health care utilization capable of assisting improved health care planning and analysis. The use of GIS was central to his research; it supported construction and application of the model; facilitated a wide range of analyses; and provided a basis for visualisation and interpretation of model results. His work indicates that GIS can also be used for better planning and analysis for MSUs services.

Fakas (1998) proposed Workflow Intelligent Business Objects (WIBOs) as the means for achieving better productivity and customer service than is possible with the current Workflow management technology (a technology for automating processes enhances the co-ordination of work). WIBOs try to further improve workflow process performance by overcoming limitations of current workflow systems and by updating workflow technology in line with the most recent trends in Information Technology, namely object-orientation, Internet/Intranets and use of intelligent agents. In the WIBO approach, workflow is modelled in terms of Process, Role and Actor WIBOs. WIBO encapsulate intelligent structure and behaviour.
Using WIBOs - that can act on users' behalf like Intelligent Agents do - to develop workflow systems that provide intelligence, autonomy, collaboration and cooperation could help in further automation, improvement and dynamic management of the process. WIBOs could also provide more dynamic allocation of work to users and resources. Java, an object-oriented language for the Internet and a communication mechanism called Java RMI were chosen for the implementation of WIBOs. A typical WIBO installation consists of a network of workflow engine and client nodes communicating over an Intranet or the Internet. WIBO approach was validated by applying it to the implementation of a workflow system for scheduling meetings.

Korpela, Tuominen, and Valoaho (1998) approached customer service from a logistics point of view. They presented a framework based on using the Analytic Hierarchy Process for strategically managing logistics service consisting of the following steps: (1) dividing the customers into logistically distinct businesses (LDBs), (2) assessing the strategic importance of the customers, (3) analysing the importance of the logistics service elements for the customers, (4) benchmarking own performance against competitors, (5) analysing the strengths and weaknesses of the own company, (6) defining logistics service plans for the LDBs, and (7) reviewing the implementation of the plans and making the needed adjustments. The use of the developed framework was demonstrated with a real application. Their framework can be used for strategically managing logistics for MSU services.

Tsaur, Chang, and Yen (2002) applied the fuzzy set theory to evaluate the service quality of airline. They mentioned that service quality is a composite of various attributes, among them many intangible attributes are difficult to measure. This characteristic introduced the obstacles for respondent in replying to the survey. In order to overcome the issue, they invited fuzzy set theory into the measurement of performance. By applying AHP in obtaining criteria weight and TOPSIS in ranking, they found the most concerned aspects of service quality were tangible and the least was empathy. The most concerned attribute was courtesy, safety and comfort.
2.2.4 Data and information for services

McFadzean (1992) investigated a real-time distributed problem-solving architecture. This stated what information should be exchanged, when it should be done, and how it should be achieved. Distributed systems are the only type of system suitable for processing many geographically separated problems. In addition, many systems also require interacting with the real world. This makes the ability to process in real-time necessary. The study investigated the mechanisms required for such systems by examining the fields of distributed artificial intelligence and real-time knowledge-based systems. Experiments were given to demonstrate the functioning of the mechanisms of the architecture. The implemented architecture successfully performs real-time distributed processing. However, it was shown that the real-time mechanisms could affect the overall coherency of the system.

Wang (1992) identified the form of and then investigated the possible implementation of a framework for a quality information system. The framework made use of the quality information generated by shop floor production processes and enhances the quality control and quality improvement activities. The quality information system (QIS) has concentrated on supporting quality improvement activities during the production stage. A knowledge based approach to diagnosing assignable causes for out of control process conditions has been researched. The approach has been implemented into an expert system termed SPC Expert. The expert system was constructed to run at two levels, a generic level for providing general suggestions for possible causes and a process specific level for indicating possible process changes related to quality deviation in production processes. These elements have been integrated into the quality information system, which can enhance quality improvement activities and process performance. His work highlights the importance of a quality information system for the proposed system of MSUs.

Prinz (1996) presented a framework for organizational information support in cooperative environments. The kernel of that framework was a meta object model that defines the construction rules for a specific organization object model. An integral component of the model was an event distribution framework that increases
the awareness about organizational changes. As a further component of the framework, a particular organizational object model was developed, and its application was illustrated. The realisation and management of the organizational information service, TOSCA, was described in detail. The architecture of TOSCA and its object-oriented service interface were presented. Such organization information support can be adapted for the services of the Hajj.

Drew (1997) was concerned with the specification of system architecture for an Integrated Information Directory Service (IIDS) which enables the management of distributed information sources and the provision of tools to reduce the information overload. A number of technologies have been used to implement the IIDS, including X.500 based scaleable directory technologies, World Wide Web gateways to enable wide user access and IDEF1X information modelling tools for designing the directory information models that mediate across a web-set of the information space. A 'personal assistant' for customised filtering of new or modified information in the directory has been developed. Finally, he explored future directions for Distributed Information Management in the context of the case studies and the Web. Such system architecture can be used to integrate and manage the information for services for the Hajj at different locations.

Pfefferl et al (1998) explained the gap in the IT use by small transport firms, and presented the use of information technologies in the transport logistics field. Then they presented the new way of intermediation in the transport and logistic, and discussed how the role of these concerns would be modified by Internet/Intranet. His work highlights the importance of IT for MSUs logistics.

Mousavi-Khalkhali (1998) focused on the role of data modelling and optimisation modelling and their application to decision support problems. The prototype design of an integrated Data and Modelling Environment (DOME) was presented. The design objectives of DOME were to support structuring of the data and structuring of the model. Intelligent Agents have introduced analytic features in Information Systems (IS) and Decision Support Systems (DSS). New workgroup computing paradigms bring together diverse specialists with different domain expertise who collaborate to support a range of users. An intelligent agent based system, which
facilitates MP model elicitation, solution, and results analysis tasks, was also presented. Through the analysis of different modelling and application requirements an architecture was proposed which employs a number of service agents designed to carry out modelling, solving, data management, and solution analysis tasks in a co-operative framework.

Evers, Loeve, and Lindeijer (2000) introduced the concept of service-oriented agile logistics and presented a generic apparatus for the design of such systems. An analysis of future communication-based logistics led to the logistic control and engineering system SERVICES. The logistic system is conceived as a “society” of interacting “self-responsible intelligent service-producing actors”, where services or functions are taken as the system-base. This meant that, instead of working with process-modules, the development of a service-oriented information-system primarily works with service-modules that program the operational interaction between client, service-producer and possibly sub-contracted service-producers. From this the supporting execution-control in the context of the service-producing units can be deduced. A case study of a high-performance deep-sea container terminal was given. The approach introduced can be adopted to assist logistics of MSUs.

Koshak and Flemming (2002) mentioned that all over the world, local authorities are moving towards managing and storing urban data in digital form. But the data storage devices used are heterogeneous and typically include relational database management systems (DBMS), GIS and CAD files. As a result, data are present in different locations on different platforms and under different schemas. This poses a problem for software applications meant to support decision-making in urban design that require input from more than one data source. They demonstrated in their paper how data warehousing, combined with object-oriented data modelling, was able to provide a general solution for this problem. Data warehousing is a technique initially developed for business applications, but is equally useful for urban design: The data warehouse constitutes a communication layer between the urban design applications and data sources. It makes the data available through a unified interface that hides the sources themselves and represents that data in terms of a general-purpose, preferably
object-oriented, model. They also describe an implementation prototype that supports different applications. The City of Makkah in Saudi Arabia provides them with real-world data and a context to test their prototype. Such data warehousing can provide the system of MSUs with detailed information about the type, quantity and time of service required taking into consideration the existing fixed services and infrastructure.

2.2.5 Planning for services

Sadler, Harvey, and Kovacs (1995) applied an operators planning process to an engineering support function, facilitated each stage of the Engineering Support planning process, and evaluated its effectiveness. The Engineering Support task was to identify the key repair, maintenance and logistic needs of emergency assistance teams and its responsibilities for service delivery. The planning task was to determine the strategic direction and specific policies most appropriate to satisfy those needs at reasonable cost. The planning process enabled the managers to identify strategic tasks to attain their service goals and start to set broad performance indicators for six service groups. Critical reassessment of the service's mission and aims was undertaken and the gap between customer requirements and achieved performance on ten key 'order-winning criteria' was determined. The result was a skeletal service operations plan containing time action plans for immediate implementation. Their research helps service providers for better planning for their service provision especially emergency assistance services.

Owen and Daskin (1998) reported on literature that explicitly addresses the strategic nature of facility location problems by considering either stochastic or dynamic problem characteristics. Dynamic formulations focus on the difficult timing issues involved in locating a facility (or facilities) over an extended horizon. Stochastic formulations attempt to capture the uncertainty in problem input parameters such as forecast demand or distance values. The stochastic literature was divided into two classes: that which explicitly considers the probability distribution of uncertain parameters, and that, which captures uncertainty through scenario planning. A wide range of model formulations and solution approaches were discussed, with
applications ranging across numerous industries. Their research can be used for selecting appropriate locations for central MSUs services.

Carnell (1999) presented a workable methodology for evaluating the balance between water resources and water demands by using a spreadsheet based risk analysis package. The technique involved statistical sampling and simulation such that samples were taken from input distributions on both the supply and demand side of the equation and the imbalance between supply and demand is calculated in the form of an output distribution. The percentiles of the output distribution represent different standards of service to the customer. The model allowed dependencies between distributions to be considered, for improved uncertainties to be assessed and for the impact of uncertain solutions to any imbalance to be calculated directly. His methodology can be used for predicting the demand for water and other supplies for MSU services.

2.2.6 Logistics, JIT and supply chain

Alemayehu (1987) analysed the benefits that would be achieved from an integrated distribution approach to the overall problem of material flow in industrial marketing. Integrated distribution system comprising 5 components were discussed. They were: facility location structure; transportation; inventory storage; material handling; and communication. The integrative system approach implied the existence of inter-relationship between the components of the integrated distribution system. He discussed the foundation of integrated distribution policy, and analysed and designed components of the integrated distribution. Then he formulated a model of systematic approach to the total distribution system design. Finally, a brief study showed how the approach to logistics management was adopted giving particular attention to the elements of warehousing, inventory management, customer's order processing, transportation and computer assisted vehicle scheduling. His work highlights the importance of planning for MSUs services in an integrated distribution framework for higher efficiency and economic return.

Lee (1994) focused on the development of the proposed Logistics-Centred-Design (LCD) methodology. The development process started with an integrated concurrent
approach, which was used as the guideline to form and implement the LCD strategy. This approach highlighted the necessary changes to the existing design environment and methodology. Therefore, the concepts of Concurrent Engineering (CE) and Computer-aided Acquisition Logistic Support (CALS) were applied for the establishment of a CE&CALS design environment and formation of the LCD strategy. An illustrative example - Warplane Availability Enhancement System (WAES) - was cited to present sufficient illustration to the implementation of this methodology. His approach can be applied for Availability Enhancement System for MSUs.

Pleschberger and Hitomi (1994) mentioned that frequent just-in-time (JIT) deliveries, widely spread throughout manufacturing and service industries, are considered a major cause of the deteriorating traffic situation. They proposed a truck-traffic coordination system that shifts truck traffic from rush hours into time zones of low traffic density. Very frequent JIT shipments become obsolete without directly restricting the number of shipments. Moreover, the concept encourages companies to use trucks that emit low noise and air pollution. The implications for JIT manufacturers were discussed and practical adjustments were explained. The effect on the traffic situation as well as on the JIT part-supply scheme was demonstrated through examples. Their work highlights the importance of taking traffic conditions in consideration while scheduling for JIT delivery of MSU services.

Cowdrick (1995) reviewed the fundamentals of Supply Chain Planning (SCP) Systems and discussed the directions of these types of systems in the 1990's, with an emphasis on solving engineering logistic problems with computer solutions. His work highlights the importance of computer applications for planning supply chain for MSU services.

Seppälä and Holmström (1995) discussed a tool developed to model the logistics networks quickly and easily and enabled comparison of different supply chains on a rough level. They used four principles when building this tool: reduction of the number of variables, creating a holistic view of the chain, use of simple calculations and the scenario approach. The tool for modelling logistics networks has been applied to different kinds of industries in various problem situations. Their work
highlights the benefits of reducing variables and the holistic and scenario approaches for model MSUs logistics.

Slats et al (1995) dealt with modelling the logistic chain. They described the developments in market demands, technology and structuring and redesign of logistic processes. They concluded that Operations Research models and techniques are well suited to analyse the local performance of logistic sub-chains and processes. But, in order to fully support the analysis of the performance of an integrated logistic chain the traditional Operations Research approach, in which the OR model is the starting point of the analysis and in which the data structure is derived from the model, is insufficient. In integrated logistic chain modelling the choice of suitable OR models should be determined by the information structure required and by the information technology available. To improve the performance of the total logistic chain an experimental environment was needed, including a set of OR models and having the capability to easily and quickly build these logistic models. They called this environment a logistic laboratory. To illustrate this concept two developed logistic laboratories were described.

Galloway (1996) explained the military approach to “designing for support”, how it was integrated into the operational requirement, and the benefits that accrued. This led to an analytical process known as logistic support analysis (LSA), which was integrated into a dynamic “supportability database” known as the logistic support analysis records (LSAR). He mentioned that the UK Ministry of Defence was fielding an Interim Defence Standard 00-60, as a contender for a NATO and ISO Standard on ILS (Integrated Logistic Support: the management approach used to predict, budget, validate and control overall support costs). He mentioned that the final edition will be a standard for contracting for ILS, provisioning, and technical documentation. The “designing for support” approach can also of benefit for operating the system of MSUs and standardizing their support procedures.

Lashbrooke and Stratton (1996) described the integrated logistics IT programme introduced in the Fleet Air Arm. It was part of a wider strategy to introduce improved management techniques. They explained the historical factors, which led to the recognition of the need for the programme, discussed some of the difficulties
encountered and the challenges faced, and identified the benefits. Their work highlights the importance of IT programme for MSUs logistics.

Chapman (1996) discussed using an integrated mix of software programs and personnel experience to facilitate production of accurate distribution costs. He analysed service as a tool to improve front-line customer relations and thereby reduce costs. His work indicates the importance of human experience to facilitate production of accurate MSU distribution costs.

Hirsch, Kuhlmann, and Schumacher (1998) mentioned that the LOCOMOTIVE consortium is developing a tool that will help create a logistic infrastructure suitable for tackling the new challenging logistics demands of the emerging production paradigm, including the assessment of environmental impacts. The tool is intended to be used by middle and upper management, to support the search for appropriate logistic solutions at the strategic decision level. Such tool can be used as well to support MSU logistics planning.

Mosterman et al (1998) described the theory, characteristics, and potential policy applications for a newly developed Decision Support System (DSS) called SMILE (Strategic Model for Integrated Logistic Evaluations). The model produces forecasts of freight flows related to the Netherlands for a large number of products and modes of transport. The model describes logistics chains at three levels: production, inventory and (multimodal) transportation. By means of a graphical user interface, the DSS assists the user with designing scenarios for simulations up to 25 years ahead and visualises the impacts of policy measures on freight flows and the environment.

Saayman and Bekker (1999) conducted a theoretical comparison of deterministic simulation versus stochastic simulation and the theoretical results were substantiated with empirical results obtained from a simple logistic simulation model using deterministic input as one alternative and stochastic input as a second alternative.

De Toni and Nassimbeni (2000) examined the role of supplier development in establishing and managing efficient buyer-supplier operational links. The paper
developed and assessed a measurement instrument for "operational" and "supplier development" just-in-time purchasing practices, followed by an examination of the relationships between the two sets, and an investigation into whether the use of "operational" and "supplier development" practices has a bearing on higher plant performance. The study empirically documented the close connection between the buyer–supplier operational link and the buyer's practices for supplier development; demonstrated that recourse to supplier development programs and their nature depend on the kind of vendor–vendee operational connection; and tested whether different plant performance outcomes result from the implementing of different "operational" and "supplier development" practices. They demonstrated that better-performing plants exhibit more advanced design and logistic links with sources, more formalised vendor-rating and ranking procedures, greater use of organisational devices for supplier-organisational integration and place greater importance on supplier assistance and training.

Franceschini and Rafele (2000) highlighted some problems relevant to the quality measurements in logistic services. "Traditional" logistic indicators were compared with the service dimensions defined in the Parasuraman-Zeithaml-Berry model. Furthermore, the problem of service indicators was analysed and discussed. Their work helps for measurement of the quality of MSU logistic services.

Stratton and Warburton (2003) mentioned that Lean supply is closely associated with enabling flow and the elimination of wasteful variation within the supply chain. However, lean operations depend on level scheduling and the growing need to accommodate variety and demand uncertainty has resulted in the emergence of the concept of agility. They explored the role of inventory and capacity in accommodating such variation and identifies how TRIZ separation principles and TOC tools may be combined in the integrated development of responsive and efficient supply chains. A detailed apparel industry case study is used to illustrate the application of these concepts and tools. Their work indicates that Lean supply can also of benefit for MSUs supply.

Lancioni, Smith and Schau (2003) mentioned that the Internet is evolving as a powerful force in the new marketplace where the nexus of competition has changed.
from individual firms to efficient supply chain networks both between firms and within industries. They explored Internet adoption patterns and operational applications in US supply chain networks. The data revealed that the integration of the Internet into supply chain management applications had increased and had moved away from indiscriminate application of novel Internet technologies towards becoming a focused endeavor with precise expectations and measurable goals. Specifically, their study found that Internet usage within supply chains is maturing as evidenced by enhanced and increased productivity, reduced costs and increased profit for participating firms. Their work highlights the importance of the Internet for MSUs supply chain networks.

2.2.7 Transportation and routing

Tareghian (1986) modelled ambulance services' organisation and operations with sufficient detail and versatility, so that it can be used by the management of any ambulance service to evaluate various operational policies or control tactics in the context of their own service. A batch, as well as an interactive simulation model, was developed. Both were shown to be capable of realistic representation of the operations of ambulance services having various organisational structures. In order to demonstrate the potential of the batch model as an evaluation tool, some operational policies and control tactics were evaluated. The evaluations were performed in the context of a fictitious ambulance service. The interactive model was used to look at the type of information that a computerised command and control system was required to provide. Based on special features incorporated into the interactive model, its suitability and application as an aid in the training of ambulance control officers was also investigated. His work shows the rule of modeling and simulation developing efficient management policy for moving services such as ambulance services.

Tsiflakos (1992) enhanced the decision support potential of railway modelling techniques by making it easier to develop and maintain railway network models. This was accomplished by exploiting advances in information technology; human-machine interaction, computer graphics and data management. A system-centred
approach to modelling railway networks was adopted, as opposed to the conventional, operational research technique-centred, methodologies. The results included the definition and implementation of a framework for the rapid construction of generic railway network models. The modelling process was automated, thus reducing the time required for conventional railway model building. His work highlights modeling as a tool for developing transportation networks. His framework can be used as well for MSUs logistics modeling. His work can be used for scheduling bus trips during the Hajj and scheduling MSU services.

Van Oudheusden and Zhu (1995) studied bus trip frequency scheduling for Bangkok taking into account the present practices, limited bus fleet size, lack of parking spaces, the fluctuating traffic conditions throughout the day, and the special feature that buses and crews were not pre-assigned to specific trips by the beginning of the daily operation. An integer-programming model was developed and two heuristic methods, one of which was based on linear programming and the other being a straightforward derivation of common bus operation practice, were presented. The resulting methodology was tested on two selected bus routes and extensive comparisons were made. In that case study, it appeared that schedules could be designed which simultaneously reduce exploitation costs and improve service to the public. The methodology allowed the bus company to systematically plan all its bus frequencies and to allocate buses to routes in a much more efficient way.

Desa (1995) was concerned with a bus fleet maintenance study for an intercity bus company. He applied the modelling approaches of snapshot modelling for problem identification and definition, and delay time modelling for evaluating the effectiveness and efficiency of the existing and alternative maintenance practices. It was found that, in a data starved situation, both the snapshot and the delay time modelling were particularly appropriate and applicable. The use of snapshot modelling has enabled the management of the company to see a comprehensive picture of their bus operation and behaviour, which resulted in several actions for improvements. His work highlights the benefits of modeling for bus and MSUs fleets maintenance.
Sadullah (1996) reviewed the transport situation in Kuala Lumpur, and identified two fundamental approaches for improvements: imposing restrictions on car usage and improving public transport performance. A disaggregate demand model linked with a simulation model of public transport operations was developed. Using the model, several alternative policies were tested to find the appropriate solutions. The current situation was simulated, and the results were used for validating the model, as well as providing insights into the nature of the problems. The eventual aim of the policies was to influence at least a 40% trip transfer from cars to public transport. He examined the effects of several bus operating strategies and several general policies. He demonstrated that the appropriate solution lies with improving the bus service, imposing restrictions on private motorisation and introducing an effective rail-based system. His work shows the efficiency of modeling and simulation in developing and testing several alternative transportation policies.

Ceric (1997) presented his experience in visual interactive modelling and simulation of the railway transportation flows for NATO strategic deployment in Bosnia from Hungary through Croatia. Development of the visual interactive model using the ServiceModel software was described, and simulation abilities of the model were presented. He showed that simulation can be done in the planning and interactive mode, and it can include breakdown in the railway operation. Based on that project the advantages and disadvantages of using the visual interactive modelling and simulation of transport networks were discussed.

Jorge-Calderon (1997) presented a demand model for scheduled airline services for the entire network of international European routes in 1989. The study included variables describing both the particular geo-economic characteristics of the area where transportation took place and the patterns of airline service, as determined by flight frequency, plane size and prices. This last group was analysed in detail, and estimates were reported for different route-length and traffic density ranges. Frequency was found to out-perform plane size as a traffic generator for shorter distance routes, but this relationship was reversed for longer sector lengths. Demand tended to be inelastic with respect to the unrestricted economy fare, and the most discounted fares were found to generate traffic on shorter distance routes.
Reeve (1998) considered the application of Stochastic Learning Automata (SLA) for distributed, lightweight adaptive routing in future integrated service communication networks. Detailed simulation models of integrated service networks were constructed and learning automata based routing was compared with traditional techniques on large-scale networks. Learning automata were examined for the 'Quality-of-Service' (QoS) routing problem in realistic network topologies, where flows may be routed in the network subject to multiple QoS metrics. It was found that learning automata based routing gives considerable blocking probability improvements over shortest path routing, despite only using local connectivity information and a simple probabilistic updating strategy. His work shows that the principles of stochastic learning automata can be used for routing MSUs.

Carey (1998) considered transport activities for which time has to be allocated or scheduled in advance. When the schedule was implemented, the time actually taken by each activity was subject to random variation, hence can exceed the scheduled time. To reduce such over-runs or lateness, and improve reliability and costs, some extra time is usually allowed for some, or all, activities in the schedule. He found that the optimal time to allow depends, in very simple ways, on a behavioural response ratio, and on the ratio of scheduled time costs to lateness costs. The model was applicable to computing optimal times for public transport timetables, for buses, trains or airlines. It was also relevant to choosing how much time to allow for each of a set of operations in production scheduling or service scheduling. His work can be used for scheduling shuttle bus services and MSUs for the Hajj.

Adamski and Turnau (1998) mentioned that in practice punctuality of transit service has been a chronic operational problem mainly due to the random environment and very high complexity of the public transport processes. This challenging problem affects both travellers (reliability of service) as well as operators (productivity and efficiency of resources utilization). They developed a simulation decision-support tool for dynamic optimal dispatching control purposes using SIMULINK package with Toolboxes. The following optimal dispatching control problems have been solved: punctuality control (which compensates deviations from schedule), regularity control (which compensates deviations from regular headway) and synchronizing
control with linear (LQ, dead-beat) feedback and control and system state constraints; LQG stochastic control with real-time estimation of the model parameters; and bus route zone control for synchronising passenger transfers or the operation of different lines on common segments of the route. The results are illustrated by 15 numerical examples. Such developments can be used for a smart booking system for Shuttle Buses for the Hajj.

Adler and Blue (1998) mentioned that the emergence of Intelligent Transportation Systems (ITS) has fostered the development of advanced traveller information systems (ATIS). These systems are designed to assist travellers in making pre-trip and enroute travel choice decisions. It is contended that while many traveller information systems are innovative and make use of cutting edge technologies, they lack real machine intelligence and therefore may be limited in their ability to service the travelling public over the long-run. Their paper presented a vision of the next generation traveller information system, termed Intelligent Traveller Information Systems (ITIS) in which artificial intelligence techniques are drawn upon to create systems capable of providing travellers with more personalized planning assistance. Such system can be used for developing an intelligent and user-friendly booking system for Shuttle Buses for the Hajj.

Perneel et al (1998) presented an approach to the long-range automatic detection of vehicles, using multisensor image sequences. The method was tested on a database of multispectral image sequences, acquired under diverse operational conditions. The approach consisted of two parts. The first part used a semisupervised approach, based on texture parameters, for detecting stationary targets. The second part of the algorithm searched for moving targets. To detect moving vehicles, any motion of the sensor must be detected first. If sensor motion is detected, it is estimated using a Markov random field model. Decision level fusion combines the results from both parts of the algorithm. Such detection approach can help detection of Buses and MSUs during the Hajj.

Hall (1998) investigated the application of neural networks to perform traffic prediction by learning the relationship between past and future traffic variations. The adaptive features of learning automata were utilised in a dynamic scheduling
mechanisms for a packet multiplexer based on measurements. By minimising the resources allocated to each traffic-flow the scheme was able to satisfy a variety of quality of service requirements whilst also maximising potential utilisation. Simulation results demonstrated that the automata were able to converge to optimal probabilities and were able to perform well over a much wider range of traffic conditions compared to traditional scheduling mechanisms. An admission control scheme was described for the adaptive scheduler in which a neural network learns the required probability based on a token bucket traffic descriptor. The mathematical form of this mapping is unknown and the neural network learns the function based on examples obtained through simulation.

de Hoogh (1999) applied, evaluated and compared methods for estimating exposure to traffic-related pollution within a GIS environment. The best methods were then used to analyse relationships between traffic-related pollution and respiratory health. His work can benefit the current research to consider traffic-related pollution within a GIS environment for the Hajj.

Chang, Yeh, and Shen (2000) developed a multi-objective programming model for the optimal allocation of passenger train services on an intercity high-speed rail line without branches. Minimizing the operator's total operating cost and minimizing the passenger's total travel time loss were the two planning objectives of the model. For a given many-to-many travel demand and a specified operating capacity, the model was solved by a fuzzy mathematical programming approach to determine the best-compromise train service plan, including the train stop-schedule plan, service frequency, and fleet size. The case study showed that an optimal set of stop-schedules can always be generated for a given travel demand. To achieve the best planning outcome, the number and type of stop-schedules should be flexibly planned, and not constrained by specific stopping schemes as often set by the planner.

Hsu and Wen (2000) mentioned that airline network design encompasses decisions on an airline network shape and route flight frequencies. Related investigations handle the trade-off between enhancing passengers' service levels and lowering the airline's operating costs by applying deterministic optimization methods. In contrast with other conventional methods, Grey theory is a feasible mathematical device
capable of forecasting airline traffic with minimum data and resolving problems containing uncertainty and indetermination. In the light of these developments, they developed a series of models capable of forecasting airline city-pair passenger traffic, designing a network of airline routes and determining flight frequencies on individual routes by applying Grey theory and multiobjective programming. A case study demonstrates the feasibility of applying the proposed models. They claim that the results of their study not only confirm the practical nature of the proposed models, but also their ability to provide high flexibility in decision making for airlines. Their approach can be used for developing a smart booking system for Shuttle Bus system for the Hajj.

2.2.8 Scheduling

Kwan (1988) described two pilot studies in bus headway integration, one on a simple bus network and the other on a mathematical programming model. His objectives included minimisation of vehicle numbers, smoothing headways on particular stretches of road, or between particular groups of routes, and combinations of these. Heuristics were used to find the best few solutions satisfying the current system targets, while the course of investigation was driven interactively by the scheduler. Problem-specific objectives that cannot be expressed in terms of the system targets were achieved by assessing the solutions found by the heuristics using specific utilities, some of which were described and presented, while the forms of others were discussed. A prototype system for interactive heuristic approach, HINT (standing for Headway INTegration) was described. A case study using HINT on a real bus network was also presented. He concluded with a summary of solution method and a review of achievements in that project. His work shows the use of heuristics to find the best few solutions satisfying the current system targets.

Matondang (1988) investigated the effects of different scheduling operating policies in real time scheduling. The simulated production system encompasses fifteen work centres. Based upon the statistical analysis it was found that the relative impact of due date assignment method, priority rule, process batch method, and operator reassignment policy or their interaction for scheduling policies in real time
scheduling to be dependent upon the measure of performance considered. The scheduling policies involving the slack time remaining (STR) priority rule were the most important of scheduling policies in minimising the tardiness of customer orders. In respect to minimising the work in progress, there was no dominant level of due date assignment method, or priority rule or process batch method of operator reassignment policy. However, the scheduling policies involving the variable process batch (VPB) method produce the best result. The scheduling policies involving the variable process batch (VPB) method were the best performers in maximising the utilisation of machine and operator. His work highlights the use of simulation for testing different scheduling operating policies in real time scheduling and the benefits of batch method to MSU scheduling.

Simpson (1988) developed a scheduling logic for computerised waiting list scheduling in a surgical unit. The factors considered were: priority of the case, operation required, predicted operation time, predicted lengths of stay, available operating times, available beds for elective surgical cases, and the case-mix requirements for individual theatre lists and wards.

Kalantarpour (1993) reported on an investigation into lead-time calculations in make-to-order manufacturing environments. The study involved an analysis of the characteristics of existing computer aided manufacturing managements systems. He demonstrated a typical problem such as imprecise timing of resource demand and poor customer service inherent in a typical batch-manufacturing environment. Further investigation was carried out on current techniques of schedule development, which established the approach of investigating the load pattern generated from an infinite capacity backward schedule and developing a number of heuristic rules to generate a feasible schedule. To appraise the approach, a direct comparison was made with a schedule using fixed lead-time based on the same performance measures. The approach developed performed more satisfactorily in delivering a feasible schedule.

Mamat (1993) investigated the problems encountered when designing strategies for assembly scheduling in manufacturing plant, in particular problems that were related to the production line. In this context, the flow of product materials through the
various steps of the manufacturing system to produce a product was modelled with specific attention given to the Just-In-Time approach. He investigated the use of SIMAN/CINEMA in developing an assembly line modelling system for manufacturing plant and tested the efficiency of the assembly line by unbalancing the station workload. His findings have highlighted and proposed several manufacturing strategies and developed a simulation model, which can provide insights in a controllable production process. The model served as test beds for investigating how pull and push principles might be incorporated and can be used in planning strategies for manufacturing plant. His work demonstrates the use of modeling and simulation for testing Just-In-Time approach for manufacturing.

Rodrigues (1994) developed a tool kit called Interactive Production Planning and Scheduling Advice System (IPPASAS), to assist synchronising the flow of work through the factory, so that excessive in-process stocks do not build up. The IPPASAS helps companies to eliminate the main barrier to synchronise manufacturing capacity constraints. It assists in the definition of a preferred product mix and permits an evaluation of possible scheduling techniques. Two of the most famous scheduling algorithms, Manufacturing Resource Planning and Theory of Constraints, were emulated by the tool kit. A visual interactive program that explains the logic and main modules of the system was provided. The approach has been tested in three real plants, which provided some insights about scheduling techniques and guide-lines for defining scheduling parameters.

Willers (1995) defined the bus crew-scheduling problem and reviewed existing computerised systems for solving crew scheduling problems in the bus industry and other transport industries. A solution strategy for the model was developed which involved solving its Linear Programming relaxation first and then using Branch and Bound techniques to search for integer solutions. A Dual Simplex approach was developed which involved a single weighted objective function and a steepest-edge algorithm. Two techniques for producing initial solutions for the dual algorithm were presented, both of which utilised the special structure of crew scheduling models. The weighted objective function and the steepest-edge Dual Simplex algorithm were also recommended for the Branch and Bound stage of solving the model. A strategy
was derived that enabled many constraints to be deleted immediately before the Branch and bound stage.

Terrier, Rioux and Chen (1995) mentioned that in general, real time scheduling algorithms provide optimal solution when the application context is well known and its behaviour completely mastered. But in practice, both the real time constraints and the tasks' characteristics are often imprecisely known. This results in sub-optimal behaviours generating failures that should be avoided. In their paper, a natural approach based on fuzzy calculus was proposed and compared with two others: the flexible/fuzzy constraints satisfaction problems, and probability based model. The showed that the fuzzy calculus is as efficient as the others, but simpler. That approach allows more realistic knowledge representations and definitions of more flexible real time scheduling algorithms.

Roy and Zhang (1996) mentioned that n/m shop scheduling is a 'NP-Hard' problem and using conventional heuristic algorithms (priority rules) only, it is almost impossible to achieve an optimal solution. Their paper advocates a fuzzy logic based, dynamic scheduling algorithm aimed at achieving this goal. The concept of new membership functions was discussed in the algorithm as a link to connect several priority rules. The constraints to determine the membership function of jobs for a particular priority rule were established, and three membership functions were developed. In order to decide the weight vector of priority rules, an aggregate performance measure was suggested. The methodology for constructing the weight vector was discussed in detail. Experiments had been carried out using a simulation technique to validate the proposed scheduling algorithm. Their work demonstrates the benefits of fuzzy logic based dynamic scheduling algorithm to MSU operations.

Fores (1996) reviewed computerised bus driver scheduling systems, with a detailed description of a system using a set-covering model to produce a schedule from a set of previously generated valid duties. That system first solves the Linear Programming relaxation problem, and then uses Branch and Bound techniques to search for a good integer solution. He implemented a specialised column generation method (a technique which implicitly considers a much larger number of duties, whilst retaining a much smaller working duty subset) within the existing set covering
system, and presented the results of tests on seven problems. Each problem instance was solved with two sizes of duty set and timings compared to those tested on the set covering system. Results showed an average reduction in execution time of 41% using column generation, and the larger data sets yielded better schedules in terms of the number of duties and the overall cost.

Malmborg (1996) investigated the potential advantages of the application of genetic algorithms (GA) to a service level based vehicle-scheduling problem. The procedure was demonstrated for a vehicle-scheduling problem with 15 locations where the objective was to minimize the time between the accumulation of correspondence at each location and delivery to destination locations. The results suggested that genetic algorithms could be effective for finding good quality scheduling solutions with only limited search of the solution space. His work highlights the possible benefits of genetic algorithms for MSUs and bus scheduling during the Hajj.

Gascon and Michelon (1997) developed an operational research model solved by a heuristic method to evaluate the number of carriers required by the system. The problem consists of determining the working schedules of the carriers. Two hospital delivery systems were compared. The efficiency of the given system was measured by the following criteria: the number of carriers and storekeepers required by the system, the carriers and storekeepers' workload, and the space used in the warehouse.

Anily, Glass, and Hassin (1998) studied a discrete problem of scheduling activities of several types under the constraint that at most a single activity can be scheduled to any one period. Applications of such a model are the scheduling of maintenance service to machines and multi-item replenishment of stock. They assumed that the cost associated with any given type of activity increases linearly with the number of periods since the last execution of this type. The problem was to find an optimal schedule specifying at which periods to execute each of the activity types in order to minimize the long run average cost per period. They investigated properties of an optimal solution and showed that there is always a cyclic optimal policy. They proposed a greedy algorithm and reported on computational comparison with the optimal. They also provided a heuristic, based on regular cycles for all but one activity type, with a guaranteed worse case bound.
Adenso-Daz, Oliva, and Gonzalez-Torre (1999) presented an on-line model, which helps in choosing the most appropriate solution for re-scheduling circulation of trains based on an intelligent exploration of the solutions space.

Ho and Lau (1999) evaluated the impact of the environmental factors, which included probability of no-show, the coefficient of variation of service times, and the number of customers per service session. The extent to which a certain environmental factor affects the performance of an appointment scheduling rule (ASR) was examined to see if there is any ASR that performs well under most operating conditions. The simulation results showed that an ASR designed to reduce customer waiting time performed very well in most operating environments considered. One commonly used ASR in real-world service systems, which schedules several customers to arrive at the start of each service session, tends to induce long customer waiting time. Their work helps service provider to reduce waiting time to their customers.

Wan and Yen (1999) studied a dynamic job shop scheduling problem to minimize total weighted tardiness. They mentioned that since it is a strongly NP-hard problem, the typical and efficient solution approach is to use dispatching rules; however, the performance of these simple dispatching rules is usually far from satisfactory. A fuzzy logic system was proposed and designed to dynamically guide the selection of dispatching rules for different problem instances at different stages by learning from fuzzy rules and previous solutions. Several experiments were designed and conducted in different scenarios to evaluate the effectiveness of the fuzzy logic system against the traditional dispatching rules. Preliminary experimental results indicated that the fuzzy logic system outperforms all the dispatching rules tested.

Hajri et al. (2000) mentioned that most scheduling problems are highly complex combinatorial problems. However, stochastic methods such as genetic algorithm yield good solutions. In their paper, they presented a controlled genetic algorithm (CGA) based on fuzzy logic and belief functions to solve job-shop scheduling problems. For better performance, they proposed an efficient representational scheme, heuristic rules for creating the initial population, and a methodology for
mixing and computing genetic operator probabilities. Their work suggests that genetic algorithm can also be used for scheduling MSUs services efficiently.

Chen and Huang (2001) demonstrated an approach, fuzzy Hopfield neural network, to solve the scheduling problems. This fuzzy Hopfield neural network approach integrates fuzzy c-means clustering strategies into a Hopfield neural network. In their investigation, they utilized this approach to demonstrate the feasibility of resolving a multiprocessor scheduling problem with no process migration, limited resources and constrained times (execution time and deadline). In the approach, the process and the processor of the scheduling problem can be regarded as a data sample and a cluster, respectively. Then, an appropriate Lyapunov energy function was derived. The scheduling results could be obtained using a fuzzy Hopfield neural clustering technique by iteratively updating the fuzzy rules until the energy function is minimized. To validate their approach, three scheduling cases for different initial neuron states as well as fuzzification parameters were taken as a testbed. Simulation results revealed that imposing the fuzzy Hopfield neural network on the proposed energy function provides a sound approach in solving this class of scheduling problems. Their work suggests that fuzzy Hopfield neural network can also be investigated to solve the MSU scheduling problems.

Dawei and Mitsuo (2001) implemented genetic algorithms (GAs) for the machine scheduling problem. The performance measure of early and tardy completion of jobs is usually to minimize simultaneously both earliness and tardiness of all jobs. As the problem was NP-hard and no effective algorithms exist, they proposed a hybrid genetic algorithms approach to deal with it. They adjusted the crossover and mutation probabilities by fuzzy logic controller whereas the hybrid genetic algorithm does not require preliminary experiments to determine probabilities for genetic operators. The experimental results showed the effectiveness of the proposed GAs method. Their method can be developed for scheduling MSUs.

Petroni and Rizzi (2002) mentioned that when scheduling jobs in a flow shop, no single dispatching rule works best for all performance criteria. Hence, it becomes paramount to assess which rule is more balanced in terms of different conflicting achievements. An alternative to the simulation-based comparison of different
dispatching rules can be represented by a linguistic based decision making method. They presented a fuzzy logic based tool intended to rank flow shop dispatching rules under multiple performance criteria. That tool was detailed with reference to a significant industrial case of a major company operating in the boilermaker industry. The results showed that the approach was robust and effective in providing a practical guidance to scheduling practitioners in choosing priorities dispatching rules when there are multiple objectives. Finally, the benefits and the shortcomings of the approach were discussed. Their work highlights the potential of using fuzzy logic for scheduling MSU service jobs.

2.2.9 Process planning and Control

Barekat (1989) reviewed the development of production planning and control systems, in particular, investigated the causes of failures in implementing Manufacturing Resources Planning systems (MRP/MRP II) in industrial environments and argued that the centralised and top-down planning structure, as well as the routine operational methodology of such systems, was inherently prone to failure. He reviewed the control benefits of cellular manufacturing systems but concluded that in more-dynamic manufacturing environments, techniques such as Kanban were inappropriate. The basic shortcomings of MRP II systems were highlighted and an enhanced operational methodology based on distributed planning and control principles was introduced. Distributed Manufacturing Resources Planning (DMRP), was developed as a capacity sensitive production planning and control solution for cellular manufacturing environments. The system utilises cell based, independently operated MRP II systems, integrated into a plant-wide control system through a Local Area Network. The potential benefits of adopting the system in industrial environments was discussed and the results of computer simulation experiments to compare the performance of the DMRP system against the conventional MRP II systems were presented. DMRP methodology was shown to offer advantages which included ease of implementation, cost effectiveness, capacity sensitivity, shorter manufacturing lead times, lower working in progress levels and improved customer service.
Fraser (1994) established a vision for the modular construction of intelligent autonomous embedded Command and Control (C2) systems, which defined a complex integration problem characterised by distributed intelligence, world knowledge and control, concurrent processing on heterogeneous platforms, and real-time performance requirements. He concluded that by adopting an appropriate systems infrastructure model, based on Object Technology, it is possible to view the construction of embedded C2 systems as the integration of a temporally assembled collection of reusable components. In his research, which draws together the themes of other published research in object oriented systems and robotics, classical AI models for intelligent systems architectures were used to specify the overall system structure, with open systems technologies supporting the interoperation of elements within the architecture. All elements of the system were modelled in terms of objects, with well-defined, implementation independent interfaces. That approach enabled the system to be specified in terms of an object model, and the development process to be framed in terms of object technology, defining an approach to Intelligent Autonomous System (IAS) development.

Basu, Huynh, and Dutta (1996) mentioned that in an increasingly automated environment, the control of material handling tasks in a goods distribution centre (DC) is a complex activity. It is necessary to control not only scheduling and routing of goods, but also material handling equipment, which is becoming increasingly autonomous and "intelligent". The problem of devising a control system so that the material flow and material handling equipment are both controlled was addressed in their paper. A discrete event modelling formalism was employed, and the concept of fuzzy logic was applied for controlling an automated goods transporting device. They claim that their approach was a significant departure from modelling control in a distribution centre. Their work highlights the potential of using fuzzy logic for managing MSU transportation tasks.

Lewis (1997) designed an integrated approach to re-engineering material flow control across the company/supplier interface, consisting of technological, organisational, and attitudinal strategies. The technological strategy took the form of a Decision Support System (DSS) that aims to maximise customer service levels
while reducing total supply chain stockholding costs and minimising the effects of demand amplification. The DSS firstly classifies demand patterns according to characteristics in the data. It then selects and assigns the best available control structures and policies to demand classes via dynamic simulation. It aims to carefully design the inventory control structure in order to reduce demand amplification exposed by the "Forrester Effect", and carefully designs the ordering systems in order to reduce the fluctuations exposed by the "Burbidge Effect". Finally, these stages were integrated into a DSS to control component inventory over its life cycle. The results included approved customer service levels and reduced purchased component stockholding costs. Improvements at the supplier interface include: more reliable schedules containing more accurate and timely information. Their work demonstrates the use of simulation for investigating customer service levels.

Da Silva Ferreira, Cavalcanti and Alsina (1999) presented a brief description of an intelligent system, used in the control of load exchange between two robotic manipulators. An intelligent tasks scheduler, that used mainly fuzzy logic to define which task will be executed in a certain instant, controlled the whole system. Tasks were used in actions and in system control. In a low level, each manipulator joint motion was controlled by an intelligent control system. Several joint motions composed action tasks. In a higher level, cooperation between both manipulators was attained through control tasks. A state diagram defined the possible action tasks sequences. According to acquired joint position information, the intelligent tasks scheduler determined, through fuzzy rules, which was the correct action task sequence.

2.2.10 Geographical Information Systems (GIS)

Rao (1994) reviewed the development of information systems in local government, including GIS, and those for strategic planning. By comparing the need for information with the potential functionality of GIS in urban policy planning, the research was able to draw up a list of requirements on the Urban Policy Information System (UPIS). He divided the UPIS into six sub-systems, in which five use existing computer software and the new one is called General Information Coordinator
(GICO). GICO links the other five and provides interfaces between sub-systems, graphic-user, and new-old modules. With such a flexible structure the UPIS could have more applications developed to meet the end-users' needs. There were five examples illustrated on planning information systems, information integration and re-generation, population analysis, transport planning and service evaluation. As an endorsement to the Corporate Information Strategy, his work demonstrated how easily an UPIS can be incorporated by using both GICO and GIS. The current research can make use of such applications of GIS for managing the information of the system of MSUs.

Kuo (1995) was concerned with the design and development of an integrated geographical information system (IGIS) based on the use of a persistent programming language called Napier88. He reported on the design considerations and the definition of the system architecture of an IGIS; the multiple data modelling of geographical data; the management of geographical data in a persistent database environment; and the implementation of a prototype IGIS. He concluded that the Napier88 language can provide a sound framework for the construction of a truly integrated GIS, although some deficiencies in the language need to be overcome.

Hobbs (1995) proposed an Artificial Intelligence (AI) technique for Geographical Information Systems (GIS). He reviewed machine learning techniques and the requirements of GIS for spatial analysis. Genetic algorithms (GA) were shown to have particular advantages for many aspects of GIS. This theme was developed and a significant change in the GA paradigm was proposed, from a domain independent representation to one, which incorporates properties of spatial analysis at its core. It was shown that a general-purpose optimisation technique, coupled with specific domain knowledge, was an effective approach for many applications and has the potential to tackle previously intractable problems. The implementation issues of the GA technique were discussed and illustrated by practical applications. His research highlights the potential of combining the strength of GIS in information and genetic algorithms for managing the operations of MSU services.

Zhu (1995) established an approach to the development of spatial decision support systems (SDSS) within an integrated framework of GIS, spatial modelling and expert
systems (ES) techniques and technologies, for supporting managers and planners in making decisions for resource and environmental management. In his approach, knowledge-based techniques were introduced into the design of knowledge-based spatial decision support systems (KBSDSS), with emphasis on the design of a representation scheme based on spatial influence diagrams and mechanisms for structuring, representing and formulating spatial problems, together with automation of the solution process. Algorithms were developed to formulate and evaluate Spatial Influence Diagrams (graphic knowledge representations for resource and environmental problems, variables, parameters and their relationships) using domain-specific knowledge in the system to represent and evaluate specific spatial problems according to the decision maker's perspective.

Kunaka (1996) developed a model of paratransit operations (many operators running one or two vehicles) in terms of interactions between demand and supply. The interactions took place in time and geographical space and were shaped by the actions taken by individual users and individual vehicle operators. Two techniques were central to the construction of the model. Simulation techniques were used to model the temporal processes and a Geographical Information System (GIS) for the spatial processes. The two were complementary to overcome the inherent weaknesses in either approach. Modules were developed to represent demand and supply at a microscopic level. The Model of Paratransit Services (MOPS) involved interfacing a GIS and external modules for dynamic processes. The model was validated against field data. Experiments were run for a case study area and the results on routing, stopping, and scheduling regimes were reported. His work demonstrates the use of simulation and GIS for investigating the interactions between demand and supply of services.

Silva (1997) designed a prototype that combines simulation techniques with the spatial data handling and mapping/graphics capabilities of a GIS, which can be developed into a Spatial Decision Support System (SDSS) for emergency evacuation planning for man-made disasters. The prototype, named CEMPS, was a product of an integration of a GIS-ARC/INFO with an object-oriented dynamic traffic simulator. The aim had been to design CEMPS so that it demonstrates how an interactive
evacuation simulator with dynamic graphics could allow experimentation with policies by providing rapid feedback from the simulation.

Dimyati (1997) explored the appropriateness of using Geographical Information System (GIS) as the backbone in proposing an integrated approach to transportation planning in Klang Valley, Malaysia. The travel demand modelling employed during the study, was extensively examined using MATLAB software and ARC/INFO GIS. An evaluation of the strengths and shortcomings of the planning process of development of new land areas and transportation system, the modelling used, and the institutional structures were evaluated as the basis for the integrated approach proposed in his research. To implement the proposals, he included an outline of strategy of actions, especially for the GIS-based proposed approach; a recommendation to reorganise institutional responsibilities, policies and legislative reform; and areas for further research. His work demonstrates the potential benefits of GIS systems and modeling for transportation planning for the Hajj.

Charnock (1998) examined the issues of linking a 2½d GIS with several model codes using a standard GIS called GRASS. The bulk of the project is concerned with examining the issues of the linkage of GIS and environmental process models. The implications of which relate to: justification of a loose-linked versus a closely integrated approach, how to achieve the technical linkage, how to reconcile the different data models used by the GIS and the process models, control of the movement of data between models of environmental subsystems to model the total system, generation of input data, including the use of geostatistic, stochastic simulation, remote sensing, regression equations and mapped data, issues of accuracy, uncertainty and simply providing adequate data for the complex models; and how such a modelling system fits into an organisational framework.

Lake (1998) applied the Hedonic Pricing method (HP is an economic technique for placing monetary values upon costs or benefits which do not have market prices), to the valuation of road transport and visual disamenity impacts, as reflected in variations within property prices. He demonstrated how a GIS could significantly improve a HP study through the calculation of a wider range of more sophisticated variables. His study illustrated how the problems of large number of variables can be
overcome through a combination of Principal Components Analysis and a Multiple Regression. Prices and values for a range of road transport and visual disamenity impacts were presented.

Wheatley (1999) investigated the changing use of GIS, and geographic information, in large-scale infrastructure management applications. He examined a number of technical developments taking place in the GIS industry. Particular attention was paid to developments in the wider information technology industry, which affect the GIS industry. Sources of data for use in infrastructure management were reviewed, and the problems and benefits of integrating this data were presented. Three case studies were described address the use of GIS to manage railway asset condition information; the use of GIS in urban transport planning; and the use of geo-coded digital video in GIS for asset management and data capture. To achieve true interoperability, detailed technical standards, in both geographic information and information technology in general, were required.

2.2.11 Modelling and simulation of systems

Cheema (1995) investigated the systems dynamic behaviour of real-time lead-time variation on a family of inventory and production control systems. That analysis made use of a Control Engineering approach to build and interrogate manufacturing control models using simulation software. It was initially based on the EXSMO simulation methodology modified as necessary to cope with modelling on-line lead-time changes. A dynamic control model used by a manufacturer of orthopaedic products to determine master production schedules was examined. Mainly a simplified model based on an inventory and order based production control system (IOBPCS) that includes a work-in-progress feedback path was used. A base parameter case was established by using an optimisation approach called the Multi attribute Utility Technique (MAUT) where key actors of a Manufacturing firm determine the relative importance of critical performance criteria. The critical importance of being able to estimate shop floor lead-time as accurately as possible was demonstrated and a number of model and system enhancements, such as the development of an adaptive lead-time algorithm and 'intelligent' lead-time estimator,
were illustrated. The influence on general system performance of the introduction of adaptive lead-time and 'intelligent' lead-time estimator was illustrated using business performance criteria such as stockout occurrences, stockturn ratios and customer service levels for a number of scenarios.

Taylor (1996) examined how airport passenger flows could be altered by a change in the arrival distribution of originating passengers at airport terminals. Three airports were modelled using a simulation tool and tested to assess how a shift in arrival distribution affects queuing and peak passenger volumes within the airport terminal. His findings showed that airport passenger terminal operational efficiency was affected by access journey time uncertainty. It also identified that passenger decision making can only be explained by various combinations of factors. Possible methods of minimising the effects of travel time uncertainty were considered. The advantages and disadvantages of access journey time uncertainty for airports and airlines were discussed. It concluded that, to be successful in overcoming negative aspects, both parties must provide a service that results in customer satisfaction. His work demonstrates the use of modeling and simulation for investigating queuing and peak customer volumes.

Buliali (1998) proposed a business process agent-based simulation modelling methodology that considers the entities taking part in a business process as agents. The methodology was confined to the simulation of business processes in units of works that have well-defined procedures for carrying out jobs and well-defined and quantifiable inputs and outputs, such as production and service operations. It accommodates classes of business rules that deal with behavioural aspects of a business process. An agent can be a human working in an organisation, a work team or a department of an organisation. An agent interacts with another agent in a closed loop as defined in a customer-performer paradigm. The interaction takes the form of communication, through exchanging messages. A message is either a request for carrying out a job or an answer. An agent schedules its jobs based on its scheduling criterion defined by the simulation modeller. The behaviour of an agent in responding to a request for service is deterministic, that is the procedure to carry out a job is fixed. The agent does not alter the procedure during a simulation run; it does
not have any learning capability. A prototype of agent-based simulation tool was built for verifying the applicability of the proposed methodology. Several case studies were presented and modelled by using this methodology. The prototype tool was used to run the models of the case studies. For comparison, an alternative modelling methodology was used to model the case studies.

Pitt (1998) investigated and evaluated the use of visual interactive simulation in the support of management decision-making. Software development work was carried out using the WITNESS discrete event simulation system. In addition, extensive use was made of Microsoft Visual Basic to generate interface tools. An approach to visual interactive simulation in healthcare based on the applied experience of the case study work was introduced. Elements of that approach included a graphical user interface, a modelling methodology and a generic hospital model, which were developed in response to the expressed requirements of managers in healthcare. This framework was used and evaluated within the case studies, which demonstrated a clear value gained from the incorporation of simulation outputs within the managerial process of healthcare. Critical issues surrounding the use of simulation in healthcare management were discussed in relation to the experience of the project work and previous studies. Finally, an assessment was given for the future directions of simulation application in the healthcare domain and in other relevant areas of management.

Robinson (1998) investigated how the quality of a simulation project can be measured, to enable the providers of simulation studies to monitor and improve the quality of their work. The main contributions of his work were: (1) The identification of a gap between customer expectations and provider perceptions of those expectations in simulation studies. (2) Demonstrating that simulation project quality is dependent, and possibly more so, on the process of delivery (functional quality), as well as on the outcome of the project (technical quality). (3) The development of a means for measuring simulation project quality from the customers' perspective (the SimQual instrument). (4) The identification of 19 dimensions of simulation project quality.
Verma, Gibbs, and Gilgan (2000) described the steps taken by a major commercial bank in the USA to redesign a critical function within its check-processing operation. Animated simulation models of the current and new process were developed to understand the relationship between process parameters, waiting times, and productivity measures. The animated simulation modelling approach was described in detail, sample results were presented and directions for further use of such an approach were provided. Such animated simulation modelling approach can benefit service providers when developing their own MSUs.

2.2.12 Artificial Intelligent, Expert Systems, and Knowledge Based Systems

Chen (1991) examined strategies for knowledge representation, acquisition and reasoning in industrially relevant machine-inspection systems. The system combined the flexibility of a knowledge-based system and the efficiency of an advanced inspection system to create a powerful paradigm. Essentially, based on the output of low-level image processing, the 'coarse-to-fine' models were generated by a learning procedure with the assistance of human operators. These models were then stored in an explicit knowledge database. Subsequently, a heuristic searching algorithm was employed to interrogate the knowledge database in order to identify the unknown articles being inspected. To ensure the efficient performance of the system, time characteristics and human-computer interfaces were also considered. Various mechanisms have been investigated and an experimental implementation has been developed to test the overall approach. A theme of the work was the stress on the implementation of knowledge management in the machine-inspection field. He showed that it is possible to integrate a set of knowledge management ideas, and incorporate the human power of reasoning to develop flexible, industrially relevant vision systems.

Ellery (1991) described an approach to the creation of missing rules for knowledge-based systems. By taking an example, which has failed to give the conclusion the expert required, it should be possible to generate a few plausible new rules. The expert can then select the required rule, a task which he should find easier than building a rule. The method used was to search forward from the example given by
the expert, and backward from the conclusion he requires. Many new rules were created by comparing states from the search processes. These were then filtered using domain specific heuristics, which can be automatically generated from the existing rule-base. These heuristics can also be refined, allowing the refinement system to improve its performance.

Kuczora (1992) described a programme of research aimed at employing knowledge-based techniques to provide a method for addressing the requirements of the project management process in the engineering domain. In particular, the integration of the two key elements of plan generation and project control using a knowledge-based paradigm was investigated. This was achieved by undertaking an analysis of the knowledge-based environment and its underlying methodologies, and then implementing a range of technological advances on that environment. These advances consist of 'truth maintenance' techniques for hypothetical reasoning, addressing the hidden problems of redundancy and ambiguity in multiple inheritance networks, an inheritance method for 'common sense' reasoning and a representation for inference - the conceptual graph. A specification for a reasoning architecture was also developed.

Abbond (1992) investigated the development of an intelligent knowledge-based supervisory control system for dynamic systems, namely industrial and medical systems. The direct expert control system investigated was a rule-based fuzzy logic controller with a self-organiser feature that provides automatic rules selection and modification. The supervisory expert control system involves combining the rule-based fuzzy logic controller as a direct control loop, and a supervision level which supervises the system globally via multi-features such as, controller tuning, self-organising, and fault detection and diagnosis. His work demonstrates the benefits of rule-based fuzzy logic controllers for controlling the system of MSUs at multiple levels.

Nie (1993) addressed three fundamental and important issues concerning the implementation of a knowledge-based system, in particular a fuzzy rule-based system, for use in intelligent control. These issues were knowledge acquisition, computational representation, and reasoning. His primary objective was to develop
systems which are capable of performing self-organizing and self-learning functions in a real-time manner under multivariable system environments by utilizing fuzzy logic, neural networks, and a combination of both paradigms which has been emphasised on the system structures, algorithms, and applications to some problems found in industrial and biomedical systems. A unified approximate reasoning model was established suitable for various definitions of linguistic connectives and for handling possibilistic and probabilistic uncertainties. For the purpose of multivariable control applications, a viable decentralized fuzzy controller structure incorporating the established reasoning mode was proposed. By assuming the unavailability of the control rule-base, a method has been suggested capable of constructing rule-bases automatically via self-learning. A class of learning control algorithms related to the rule-based construction has been proposed with mathematical proofs of learning convergence.

Tieperman, Inman, and Pick (1994) highlighted that Expert Systems can provide a competitive edge for companies in the service sector. Reasoning from examples in health care, education, financial services, transport and marketing; they argued that expert systems could preserve and distribute knowledge, enhance standardization, improve service and reduce costs.

Leopold (1994) proposed and applied a method of overcoming the problem of knowledge elicitation from formally trained experts during the development of a knowledge-based system. Classical methods were also assimilated. A rule-based knowledge-based system named ARAMIS (Allocation of Resources And Management of Improved Supplies). Key characteristics of the system and its utility were considered in the study, leading to an identification of its advantages and drawbacks.

King (1995) introduced and proved the efficacy of a new method aimed at automatically building a knowledge based system economically, rapidly and accurately, in a way that overcomes the deficiencies of the other techniques (neural networks, genetic algorithms, case-based reasoning and data-mining). This was achieved by designing and implementing a software tool that could extract a significant portion of the knowledge in a deep knowledge base from Computer-
Aided Design (CAD) files. The resulting knowledge-based system was capable of detecting faults in simulated operation data. Furthermore, that knowledge may be extracted and structured automatically. This has the effect of significantly reducing the development time, errors and cost of producing an expert system capable of diagnosing faults, issuing warnings/advice, and having explanation facilities (thus addressing the deficiencies of neural networks, etc). Additionally, it was established, based on evidence obtained from testing the diagnostic system, that the new knowledge acquisition technique could also be used to generate other applications, such as an on-line intelligent operator-training aid (an Intelligent Tutoring System).

Booth (1995) was concerned with two separate but related types of methodological endeavour. He described how a methodology to support the development of knowledge-based procedures was composed using the action research method. He examined both the relevance of action research to methodology composition and the characteristics of the methodology produced. The project confirmed the suitability of action research to the development of a system methodology. The major advantages of his approach were that it supported the analysis of business requirements and provided for the selection of the most appropriate technology to support these requirements.

Lam (1995) explored the feasibility of using a knowledge-based decision support system for planning and scheduling the production and delivery of ready-mixed concrete. Due to the peculiar characteristics of the product, which has a "shelf life" of only a few hours, the unpredictable nature of the operating environment, the planning and scheduling problems of the production and delivery activities are usually unstructured and complex. A prototype called ISRMC has been successfully developed as a result of a study of the production and delivery process and detailed collection of knowledge from various sources.

Newton (1995) investigated the provision of an Applications Specific Language suitable for expressing solutions to the Naval Data Fusion problem (the process of combining data from a ship's multiple sensors, to provide a coherent view of the tactical environment of that ship), using the DRA approach (using a Blackboard Knowledge-based System paradigm, and a sea-going automatic data-fusion system).
The language is known as the Data Fusion Language (DFL) and was intended for use by knowledge engineers working in the Naval domain. The grammar of the DFL has been formally expressed using the Backus Naur Form (BNF), whilst the semantics of a DFL program were described using a combined Vienna Development Method (VDM) and Communicating Sequential Processes (CSP) model.

Mehmi (1995) developed an expert system to look at the problems of solid waste collection in developing countries. The expert system was built up using five knowledge bases: Data, Infrastructure, Transport, Social, and Storage. The Xi Plus expert system shell was used in which knowledge representation was incorporated using production rules. The interaction between the expert system and the user was enhanced by the built in help/advice and explanation menus plus facilities within the expert system shell itself. The expert system could access other software such as a spreadsheet to determine the financial costs of a collection system or obtain in-depth knowledge/explanation of questions through the help command contained within word-processing files.

Cao, Rees and Feng (1995) developed a method for analysis and design of a fuzzy controller for a class of fuzzy discrete-time systems. The method was based on a dynamic fuzzy state-space model. It was shown that the closed-loop fuzzy system can be represented by a dynamic interval system, and thus the methods of stability analysis in uncertain linear system theory can be used to analyse the global stability of the closed-loop fuzzy system. Some examples were given to illustrate the application of the method.

Wang (1996) presented a methodology for the design and implementation of a prototype knowledge-based system for recipe management in batch chemical processes. The system was named as a Recipe Management System (RMS). The primary objective of the RMS was to achieve automatic recipe transformation through the application of artificial intelligence techniques. In the RMS, object-oriented programming (OOP) was used to represent both the process equipment units and the product recipes in batch processes and the key work analysis technique was applied for symbolic processing. The mechanisms of the RMS were demonstrated through three examples and an industrial case study. The results demonstrated that
the challenge of efficient recipe transformation and management can be solved using OOP and KBS techniques. It was envisaged that the RMS would be useful to a variety of personnel involved in batch process design, operation, control and management.

Khan (1996) investigated the reasons for the failure to keep the Master Production Schedule (MPS) realistic and achievable. A knowledge-based approach was applied to improve the effectiveness of the MPS. A prototype system named as Knowledge-Based Master Production Scheduling (KBMPs) was developed with the objective to help and guide the master scheduler in the creation of a realistic MPS. Rules and conditions were incorporated into the system to identify, classify and rectify any problems on critical resources. The knowledge-based system can test the validity of a tentative master production schedule and identify the bottlenecks, which will prevent its actual achievement. It incorporated a number of rules that can be used, taking into account the circumstances and constraints, to provide advice about the possible management decisions needed to overcome the effects of bottlenecks. The knowledge based system makes it possible to consider all alternative solutions and allow the management to select, in an interactive and timely manner, the best possible solution after taking into account the likely implications. In order to provide the best possible solution the KBMPS system also takes into account the customer and order priorities and makes use of the simulation based "What-If" analysis to evaluate any changes to the MPS recommended by the management and suggests possible alternatives to adjust the capacities. It was demonstrated that realistic outputs obtained from this system were realistic inputs to an MRP system, and play a significant role in the success of the MRP.

Nukala (1997) developed three intelligent control architectures based on the modularity principle. A modular fuzzy logic controller (MFLC), a modular neural network controller (MNNC), and a modular neuro-fuzzy controller (MNFC) have been developed. Besides the extensive simulation studies, all the developed controllers have been experimentally evaluated on a real CBIP rig. The study has completed the whole cycle of design development evaluation of intelligent controllers based on fuzzy logic, neural networks, and neuro-fuzzy technologies.
Said (1997) showed that a knowledge-based system is an effective tool to help novice simulation users interpret and understand simulation output. A simulation program, which adopts the discrete-event simulation approach, simulated the behaviour of a local area network protocol. The knowledge-based system carried out the 'analysis' of the simulation output covering the protocol efficiency and throughput. The knowledge-based system summarised the simulation output and provided explanations to a conclusion arrived at. The strategy for building the knowledge base using production rules was also elaborated. An experiment was carried out to evaluate the effectiveness of the prototype. The results showed that although some responses were mixed, there was evidence to suggest that the knowledge-based simulation system environment is beneficial to the target users.

Loughlin (1998) showed how much expertise may be modelled in a knowledge-based system. Two techniques for helping to ensure that quantitative scientific knowledge is only used in the correct context were presented. The first technique, attaching quantitative constraints that were evaluated during problem solving to formulae. The second technique, by dividing knowledge into ontologies describing scientific domains and physical entities. Techniques for suggesting the ontologies to be used for solving a particular problem were also presented. These techniques had been implemented in a system known as the Quantitative Problem Solver (QPS), which has been used to solve a number of problems from varying domains. Via a forward chaining process, a knowledge base of scientific formulae may be used to rewrite design criteria as equivalent materials database queries. A review of related problem solving systems was also given along with comparisons against the developed system.

Halhal (1998) was concerned with the optimal improvement of water distribution systems subject to limits of funding. A Structured Messy Genetic Algorithm (SMGA) was specially developed, incorporating some of the principles of the Messy Genetic Algorithm, such as strings, which increase in length during the evolution of designs. SMGA was combined with a multi-objective approach, using capital cost and benefit as dual objectives, enabling a range of non-inferior solutions of varying cost to be derived. The algorithm was shown to be an effective tool for that
optimisation problem, being particularly suited both to the multi-objective approach and to problems, which involve the selection of small sets of variables from a large numbers of possibilities.

Ngai and Wat (2003) described the research and development of a fuzzy expert system for hotel selection. A prototype system, called hotel advisory system (HAS), has been designed and developed to assist tourists in conducting hotel selection using fuzzy logic. To evaluate the performance of HAS, selected practitioners in the Hong Kong hotel industry and potential users from twelve nations were invited to participate in testing the system. They mentioned that the potential users and hotel experts rated highly on the effectiveness and the usability of the system. The results of the prototype evaluation is said to be satisfactory and support the contention that HAS performs its functions as expected. The viability of HAS as an effective procedure for hotel selection has been ascertained by the positive feedback obtained from the survey questionnaires. Using HAS makes hotel selection simple because it can incorporate the linguistic terms that are normally produced by tourists.
2.3 The Research Work

The literature review has revealed that no such system of MSUs has been developed or investigated for the Hajj in particular, nor with its comprehensive perspectives for the large-scale event industry in general. It also showed that many available techniques are promising and could be used for developing the proposed system of MSUs at macroscopic and microscopic levels.

2.3.1 The Goal of the Research

The goal of the research can be set as follows:

"To investigate, develop, and validate the proposed system of Mobile Service Units (MSUs) for the Hajj, for serving the expected number of 4.8 million pilgrims by year 2025, based on the new Master Plan for the cities of the Hajj".

2.3.2 Research Questions

Based on the above goal for the research and once the proposed system of MSUs was viewed in details, many questions arise regarding technical and practical issues of the system such as:

- What are the opinions of the service providers of the Hajj regarding the proposed system of MSUs?
- What services are suitable to be MSUs?
- Is it technically possible to make the different types of services mobile?
- How would these MSU look, and how can they be made?
- Will the proposed system of MSU work for the Hajj?
- How can the system of MSUs be managed or controlled for higher efficiency and utilization of resources with improved customer satisfaction?
- How can the movement of buses and MSUs be managed successfully?
• Will the capacity of the road network and the tight program of the Hajj allow for a successful movement of both pilgrims and mobile services?

• How much reserve of MSUs is needed?

• What benefits would MSUs provide for the visitors participating in the Hajj, service providers, governmental bodies, the society, the environment and the local economy?

Therefore, this research work will attempt to address the above questions in order to investigate, develop, and validate the proposed system of Mobile Service Units (MSUs) for the Hajj.

2.3.3 The scope of the Research

The system of MSUs can be investigated from a different point of view based upon different disciplines as shown in Figure 2.1. However, this research would focus on topics related to multidisciplinary engineering in general and mechanical engineering in particular. The system will be viewed as a very large plant, covering four cities, where interactions take place between demand and supply for services at different locations of the master plan for the four cities of the Hajj. Investigating the interaction mechanisms between the different components of such a system and developing an approach to control these processes, will form the major part of this research work. Techniques from different disciplines will be investigated and adapted to enrich the development of the proposed system of MSU.

Figure 2.1: The proposed system of MSUs can be investigated from the point view of different disciplines
2.3.4 The Outline of the Research

Figure 2.2 shows the outline of the research. After giving a brief background on the event industry, the Hajj and the proposed system of MSUs in Chapter One, a literature review was conducted in macroscopic scale in Chapter Two, to overview different areas related to the proposed system in general and the current knowledge in that field. Afterwards, in Chapter Three, the system of MSUs will be investigated from the point of view of service providers in order to highlight their perceptions to such a system based on their experience in the Hajj. The investigation towards verifying the possibility of physically making such a large system of MSUs, the resources for making them and integrating them within the master plan is conducted in Chapter Four. On the other hand, it is quite difficult, risky and very costly to establish such a large system in such a mega event of the Hajj without prior confirmation of the ability to operate and manage them with a satisfactory level of service. Therefore, a general model for the whole system is developed and simulation is used intensively to develop the control for the system as will be described in Chapter Five and Chapter Six which together form the main body of this research. The outcome of the investigations conducted in chapters 3, 4, 5 and 6 are presented and discussed in detail in Chapter Seven which also highlights suggestions for taking the project forward and areas for further research. Chapter Eight concludes the research by summarizing the main investigations conducted and highlighting the main findings of the research. Further details and illustrations are giving in Appendices at the end of the thesis.
2.4 Closure

This chapter reviewed the literature in topics and technologies related in general to the proposed research work. These technologies are valuable in developing the components of the proposed system of MSUs at macroscopic and microscopic levels. The goal, research questions and the scope of the research were addressed. The outline of the research was giving which will be described in details in the coming chapters.
CHAPTER THREE

Investigation of the Proposed System of Mobile Service Units from the Point Views of Service Providers

3.1 An overview of Chapter Three

It is quite important to investigate the need for the proposed system of MSUs and their constraints from the point of view of service providers, owing to their wide experience in providing services for the Hajj and since they are the main stakeholders for the proposed system of MSUs once implemented. This chapter describes the work conducted toward this investigation and presents its main findings. The contents of Chapter Three are organized as follows:

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3.10 Closure 3-20
3.2 The methodology for the investigation

Since the data required is based on human experience, the methodology selected for the investigation is as follows:

1- Conducting a series of field visits, interviews, presentations and seminars to discuss the concept with Hajj service providers.

2- Selecting, developing and designing a tool (a questionnaire) for collecting data regarding the opinions of service providers for a variety of aspects related to the concept of MSU.

3- Distributing the questionnaire to the managers and supervisors responsible for providing different services to pilgrims in Makkah and Al-Mashaeer during the Hajj.

4- Analysing the data collected using an appropriate statistical program (SPSS).

5- Extracting the opinions of service providers and selecting the most suitable services to be MSUs based on the analysis of the data collected by the questionnaire.

3.3 Selection of the tool for data collection

It was important, for this study, to select the most appropriate MSU in the light of the opinions of the actual users, the service providers, to benefit from their experience, and to focus on developing the most acceptable types of proposed MSU. Such data, which depends on the opinion and experience of the respondents, can be best gathered through interviews or questionnaires.

Interviews have the advantage of close contact with respondents and allow further explanation and discussion. However interviews were found not suitable for this study for many reasons:

1- It is not appropriate to send students to conduct interviews with officials and supervisors who are usually of high working class. Thus, a large number of highly qualified interviewers are needed to carry out a large
number of interviews within the short time of the Hajj season. The high cost for paying such qualified interviewers exceeds the limited budget of this study.

2- The Hajj season is very short, which makes the respondents very busy and more likely not to accept to be interviewed. Many respondents would not be available before or after the Hajj season as most of them work temporarily.

On the other hand, questionnaires have many advantages that make them suitable for this study, such as:

1- Questionnaires can be left with the respondents for some time and be collected by the end of the Hajj season, which allows enough time for the respondents to read, understand, and answer the questions at their convenient time.

2- There are many items in the questions, which the respondents may prefer to read carefully before answering, rather than just hearing them from interviewers.

3- Questionnaires give the respondents more privacy to answer critical questions, which enhances obtaining unbiased answers.

4- Distributing and collecting questionnaires can be carried out by a few trained students at low cost within the budget of the study.

However, the main disadvantage for questionnaires is that they may be ignored or binned, giving low return ratio. Therefore, a good distribution plan and follow-up procedure need to be considered to overcome this disadvantage.

3.4 Questionnaire design

A questionnaire has been designed as the main tool to collect the information required from the managers and the supervisors responsible for providing services to pilgrims in Makkah and Al-Mashaeer during the Hajj. The procedure was as follows:
3.4.1 Questionnaire objectives

1- To identify the managers’ and supervisors’ views regarding the adequacy of the existing services provided to pilgrims.

2- To identify the managers’ and supervisors’ views regarding the feasibility of the different types of proposed MSU and to give them the chance to propose more MSUs if needed.

3- To identify the possible factors that may hinder the use of MSU.

4- To get feedback from the managers and supervisors for different aspects related to the proposed MSU.

5- To identify the demographical characteristics of the managers and supervisors who are responsible for providing services to pilgrims, for better understanding and interpreting their answers.

The questionnaire was designed in the light of the facilities and support services available at the Custodian of the Two Holy Mosques Institute for Hajj Research (CTHMIHR) for questionnaire distribution and data entry, to benefit from the good reputation and its strong connection with all governmental bodies and private sector working in the Hajj. The selection and wording of the questions were based on six years experience of the researcher on Hajj studies, particularly in the project of ‘Exclusive Roads for Shuttle Buses Service (ERSBS)’. (Othman, 1991 & 1998, CTHMIHR I & 2, 1996 & 1997)

A draft of the questionnaire was tested among some Saudi Ph.D. students at Loughborough University who had some experience of the Hajj. Their comments helped to make the final modification to the questionnaire both in wording and style. The pilot questionnaire showed that the time to answer the questions were suitable and acceptable, as they can be answered within twenty minutes. This piloting was important to insure that the questionnaire is self-explanatory and can be understood and answered easily by the respondents without any assistance.
3.4.2 Type of questions

Two types of questions are mainly used in questionnaires: open-ended and closed-ended questions (Hague, 1993). Open-ended questions help to explore the thought of the respondents and the reasons behind their answers and give them strong feeling of contribution to the study. However, open-ended questions are difficult and time consuming to analyse; as different respondents give a wide variety of different answers to the same questions, which needs further understanding, grouping, and analysing. Furthermore, the handwriting and wording style for some of the respondents makes it very difficult to read and understand their answers. The effort of writing puts some limitations on the number of questions to ask, as a large number of open-ended questions requires a very long time to answer, which may hinder some respondents from answering the questions or forces them to make very short, ambiguous answers.

On the other hand, closed-ended questions give the respondents a variety of possible answers from which they select the most appropriate ones. This allows the respondents to answer more questions in a relatively short time, and gives the researcher the possibility of analysing the answers based on predefined categories. However, there is a risk that not all the possible answers were given, and the respondents may be forced to give alternative answers or to leave some questions unanswered.

Appendix A shows a translation of the questionnaire used for this study (The original one was in Arabic language; the native language for the respondents). The type of questions used in this questionnaire were mainly closed-ended questions that usually include one open ended answer (Other:...........), to allow the respondent to give another answer that was not included in the options. This approach proved to be very useful while checking the returned questionnaires since some respondents (very few) misunderstood some answering options and gave their own answers, which later allowed the researcher to redesignate their answers according to the correct category.

Open-ended questions were also used in the questionnaire after the closed-ended questions to encourage the respondents to give their own comments, views, and any
related matters not mentioned in the questionnaires. This proved to be very useful, as some respondents gave their comments that explained their answers. Open-ended questions also helped to give the respondents the respect and the feeling of contribution, rather than just answering questions with predefined answers with no room for their comments.

Rating questions were presented in tabular forms and preceded by examples and instructions asking the respondents to tick ( ) inside the proper box for the answers that most reflect their opinions. These table forms and ticking processes helped to make answering the questions easier for the respondents, and gave a visual meaning for rating values. (See for example question 9, Appendix A). This table form proved also to be easier for the researcher to check data entry and not to be mistaken by any handwriting errors.

The rating scales for questions 6, 9, and 11, were a 4-point scale, two in the negative side of the scale, and two in the positive side. The scale was made of an even number of points to encourage the respondents to define their opinions in the negative or the positive side of the scale. However, a fifth point for ‘I don’t know’ was used to encourage those who disagree with any of the given answers or unsure of their answer to use it rather than forcing them to one side of the scale. A four-point scale was used for these questions because it is clearer and easier to answer compared with a six-point scale, especially for a large number of items, and because a general opinion is required rather than a highly defined opinion; taking into consideration that the concept of MSU is proposed and not yet implemented.

The first five questions were designed to give demographic information about the respondents. They were: 1) Their work sector during the Hajj; 2) The nature of their work whether permanent through the year or temporary during the Hajj; 3) The location of their permanent work other than the Hajj; 4) The type of their work during the Hajj: 5) Their experience in terms of the number of times they had joined the work during the Hajj.

Question number six asked the respondents to indicate the services provided for pilgrims in Makkah and Al-Mashaeer by the departments they worked for during the
Hajj. They were asked also to evaluate all services (whether provided or not provided by their departments) to show their opinions whether they consider them sufficient or not sufficient for pilgrims in Makkah and Al-Mashaeer. Question number seven asked them to estimate the maximum number of pilgrims who used the services provided by their departments in Makkah and Al-Mashaeer in any given day.

Number eight was not a question, but rather a brief description of the proposed solution for developing and providing sufficient integrated services for pilgrims in Makkah and Al-Mashaeer using MSUs, to give the respondents a general understanding of the proposed MSUs, and to clarify any misunderstanding due to their previous experience with other trials or proposals. This brief description may have had some positive bias to the respondents, but using probable phrases rather than definite ones reduced this effect. Further, this bias is to be reduced by the natural tendency for people to reject change.

Question number nine is the main question, it was designed to obtain the opinions of the respondents regarding the feasibility of putting different types of services into trucks or trailers as MSUs to serve pilgrims in Makkah and Al-Mashaeer. The total number of the suggested services was 59 types covering almost all the facilities and services needed by the pilgrims. These services were derived based on the services that are currently provided during the Hajj, as suggested by the Master plan or proposed by the researcher. This question was followed by question number ten which is an open ended question asking the respondent to suggest any other services and facilities suitable to be mobile.

Question number eleven was designed to estimate the level of hindering for some factors that might affect the implementation of the system of MSUs in Makkah and Al-Mashaeer. These hindering factors were divided into two groups relating to the existing conditions or to the concept of MSUs. This question was followed by question number twelve asking the respondent to specify any other factors not mentioned in the previous question that may hinder the implementation of MSU in Makkah and Al-Mashaeer.
Question number thirteen asked the respondent about his general opinion in putting most pilgrim's services in lorries and trailers that are transported from one place to another before and after the movement of pilgrims through the roads assigned for the shuttle buses system. This question came at the end of the questionnaire where the respondents had gained a good understanding of the different types of the proposed MSUs and the possible hindering factors that may affect them. The answer was made on a 6-point scale to get a more precise answer. A seventh point for 'I don't know' was introduced to encourage the respondent to avoid giving a wrong answer if he is not sure or disagreed with any of the given answers.

Question number fourteen was an open-ended question asking the respondents to specify any relevant suggestions or opinions. The last question asked the respondents to use additional papers if they had more suggestions, and to attach any reports or publications they may feel important to the study.

At the end of the questionnaire contact address were given for the respondents to send the answered questionnaires if nobody collected them, and to send any further suggestions or comments.

3.4.3 Questionnaire distribution and collection procedure

The Hajj season for year 2000 was in March. The researcher decided not to go to Makkah to distribute the questionnaire, since it was designed to be self explanatory, and questionnaire distribution facilities were available and done as a routine at the CTHMIHR (the employer of the researcher), Umm Al-Qura university, Makkah, Saudi Arabia. The final questionnaire (in the Arabic language) and written instructions for distributing them were sent to the Institute by the end of February 2000. The Deputy Dean of the Institute (Dr. S. Barhamain), suggested some useful modifications both in the covering letter and distribution process. The researcher approved these suggestions that were intended to improve the response rate. A staff member at the CTHMIHR (Dr. G. Elkahlout, Department of Information and Support Services), kindly supervised the process of distributing and collecting the questionnaire.
Two experienced undergraduate students, who were residents in the city of Makkah, were assigned the task of distributing the questionnaire. They were selected of Saudi nationality to ensure better communication with Saudi managers and supervisors, and residents of the city of Makkah to ensure that they knew where to distribute the questionnaire. The experience they obtained during previous work with the Institute was vital to ensure the quality of their work. The tasks allocated to the students were:

1- Distributing the questionnaires to governmental bodies, pilgrimage establishments and private sector offices and camps by the beginning of the Hajj (Pilgrimage) season.
2- Ensuring that these questionnaires had arrived at their destinations.
3- Collecting the completed questionnaires after the Hajj season within one week.
4- Informing the supervisor about any problem affecting their job.
5- Delivering formal follow-up letters signed by the dean of the institute encouraging respondents who were reluctant or not convinced to fill or to return the questionnaires.

The questionnaires were distributed to almost all available governmental offices, pilgrims' establishments, and the private sector, which had offices or camps in the city of Makkah. The total number of forms distributed was more than 500 questionnaires. The total number returned was 297 questionnaires. This response rate is very high and can be due to the good reputation of the CTHMIHR Institute among the governmental and private sector working in the Hajj, and the successful distribution, collection, and follow up procedures.

3.4.4 Data entry and revision

The returned questionnaires were coded and checked manually, fed to computer using appropriate software, and rechecked manually. This stage was done at the CTHMIHR Institute using the available staff and facilities. Final data file and original questionnaires were received by the researcher by mid June 2000. Since the data file contained more than 35,000 data entries, the researcher spent several weeks
checking all data entries and compared them manually with the original of each questionnaire. Late arrival questionnaires were also checked and entered.

3.5 Sample profile and data summery

The revised data was analysed using a powerful statistical package (SPSS for windows V.9). The software allowed the researcher to exclude "missing values" and "I don't know" responses from being considered in the statistics, and analysing the data (Bryman and Cramer 1997, Howitt and Cramer 1999). The following is findings of the analysis:

3.5.1 Work sector

The distribution of respondents' work sector (Table 3.1) shows that the majority work in the governmental sector (50%), pilgrimage establishments (33%), and private sector (9%) fewer are from Tawaeef services (6%) and other sectors (1.4%).

Considering that pilgrimage establishments and Tawaeef services are private sector (under governmental supervision), it can be said that 48% of the respondents were private sector and 50% were governmental sector, which reflects some balance in the samples representing private and governmental sectors.

<table>
<thead>
<tr>
<th>Work sector</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Governmental sector</td>
<td>148</td>
<td>50.3</td>
</tr>
<tr>
<td>Pilgrimage Establishment</td>
<td>98</td>
<td>33.3</td>
</tr>
<tr>
<td>Tawaeef services</td>
<td>17</td>
<td>5.8</td>
</tr>
<tr>
<td>Private Sector</td>
<td>27</td>
<td>9.2</td>
</tr>
<tr>
<td>Other</td>
<td>4</td>
<td>1.4</td>
</tr>
<tr>
<td>Total</td>
<td>294</td>
<td>100.0</td>
</tr>
</tbody>
</table>
3.5.2 Duration of work

Table 3.2 shows the duration of work for the respondents. It shows that 53% of the respondents were working permanently in the same sector as in the Hajj season, while 46% were working temporarily during the Hajj season only. Very few respondents (1%) were from other categories. It can be concluded that nearly half of the managers and supervisors, in the sample, were working temporarily for the Hajj season in a sector other than their permanent work sector.

<table>
<thead>
<tr>
<th>Duration of work</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent work through the year</td>
<td>156</td>
<td>52.9</td>
</tr>
<tr>
<td>Temporary work for the Hajj season</td>
<td>136</td>
<td>46.1</td>
</tr>
<tr>
<td>Other</td>
<td>3</td>
<td>1.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>295</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>

3.5.3 Location of the permanent work

Table 3.3 shows that the majority of the officials and supervisors (90%) are working in the Makkah district (county), while few (9%) are from other districts of Saudi Arabia. This result showed that most officials and supervisors are familiar with pilgrimage areas and closely in touch with the Hajj (pilgrimage) activities. Only 3 cases (1%) were accidentally found working permanently outside of Saudi Arabia, as the questionnaire was not supposed to be distributed to Non-Saudi sectors.

<table>
<thead>
<tr>
<th>Location of the permanent work</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Makkah district (county)</td>
<td>263</td>
<td>90.4</td>
</tr>
<tr>
<td>Another district in Saudi Arabia</td>
<td>25</td>
<td>8.6</td>
</tr>
<tr>
<td>Outside Saudi Arabia</td>
<td>3</td>
<td>1.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>291</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>
3.5.4 Type of work during the Hajj

Table 3.4 shows that the working experience of the respondents varies and covers most types of work. Fieldwork and field supervision experience are the most common having a combined percentages of 48%. This reflects the high representation from the point of view of practical experience, which is valuable especially for evaluation questions.

Office work experience is also well presented (24%) which reflects a good representation from the administrative point of view. The general supervision work experience has relatively high percentage (19%), which reflects a good representation of top management and supervision points of views. Coordinating work has the least percentage (7%), due to small proportion of managers and supervisors who are only coordinating with others rather than doing any of the other types of work. Very few respondents (1.4%) do work other than those mentioned above.

<table>
<thead>
<tr>
<th>Type of work</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>General supervision</td>
<td>56</td>
<td>19.0</td>
</tr>
<tr>
<td>Field supervision</td>
<td>67</td>
<td>22.7</td>
</tr>
<tr>
<td>Coordinating work</td>
<td>21</td>
<td>7.1</td>
</tr>
<tr>
<td>Fieldwork</td>
<td>75</td>
<td>25.4</td>
</tr>
<tr>
<td>Office work</td>
<td>72</td>
<td>24.4</td>
</tr>
<tr>
<td>Other</td>
<td>4</td>
<td>1.4</td>
</tr>
<tr>
<td>Total</td>
<td>295</td>
<td>100.0</td>
</tr>
</tbody>
</table>

3.5.5 Work experience in the Hajj

Table 3.5 shows the experience of the respondents in the Hajj. It can be seen that almost half of the respondents (48%), are very highly experienced and had worked in the Hajj more than 10 times, and 17% have very good experience as they had worked from 6 to 10 times in the Hajj. It can be concluded that almost 2/3 of the respondents (65 %) are very experienced in working during the Hajj. Moderately experienced managers and supervisors who had worked from 3 to 5 times with their percentage of
16 % are almost the same as those with little experience who had worked in pilgrimage seasons twice, once, or not at all with their combined percentage of 19 %.

Table 3.5: Work Experience in the Hajj

<table>
<thead>
<tr>
<th>Work Experience</th>
<th>Frequency</th>
<th>Percent</th>
<th>Cumulative Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>More than (10) times</td>
<td>141</td>
<td>48.1</td>
<td>48.1</td>
</tr>
<tr>
<td>From (6) to (10) times</td>
<td>49</td>
<td>16.7</td>
<td>64.8</td>
</tr>
<tr>
<td>From (3) to (5) times</td>
<td>47</td>
<td>16.0</td>
<td>80.8</td>
</tr>
<tr>
<td>Twice</td>
<td>26</td>
<td>8.9</td>
<td>89.7</td>
</tr>
<tr>
<td>Once</td>
<td>27</td>
<td>9.2</td>
<td>98.9</td>
</tr>
<tr>
<td>Zero</td>
<td>3</td>
<td>1.0</td>
<td>100.0</td>
</tr>
<tr>
<td>Total</td>
<td>293</td>
<td>100.0</td>
<td></td>
</tr>
</tbody>
</table>

3.5.6 Number of pilgrims served by respondents department

The respondents were asked to estimate the maximum number of pilgrims using all the services provided by their departments in Makkah and Al-Mashaeer in any given day. Table 3.6 shows that 21% of the departments serve small number of pilgrims (less than 500 pilgrims/day), 36 % serve moderate number of pilgrims (from 500 to 5000 pilgrims/day), while 43 % of the departments serve high number of pilgrims (more than 5000 pilgrims/day), including those stated another number much more than 5000 pilgrims/day.

It can be concluded that the majority of the respondents were working in departments responsible for providing services for quite large numbers of pilgrims, which reflects their experience as service providers for large numbers of people.
### Table 3.6: The Daily Number of Pilgrims Using all the Services Provided by Respondent's Department in Makkah and Al-Mashaeer.

<table>
<thead>
<tr>
<th>Daily Number of Pilgrims served</th>
<th>Frequency</th>
<th>Percent</th>
<th>Cumulative Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than (100) pilgrims</td>
<td>28</td>
<td>10.4</td>
<td>10.4</td>
</tr>
<tr>
<td>From (101) to (500) pilgrims</td>
<td>29</td>
<td>10.7</td>
<td>21.1</td>
</tr>
<tr>
<td>From (501) to (1000) pilgrims</td>
<td>33</td>
<td>12.2</td>
<td>33.3</td>
</tr>
<tr>
<td>From (1001) to (5000) pilgrims</td>
<td>64</td>
<td>23.7</td>
<td>57.0</td>
</tr>
<tr>
<td>More than (5000) pilgrims</td>
<td>68</td>
<td>25.2</td>
<td>82.2</td>
</tr>
<tr>
<td>Another number (much more than 5000 pilgrims)</td>
<td>48</td>
<td>17.8</td>
<td>100.0</td>
</tr>
<tr>
<td>Total</td>
<td>270</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

#### 3.6 Sufficiency and Provision of services for pilgrims

The respondents were given a list of services provided for pilgrims, and asked to indicate the services provided to pilgrims in Makkah and Al-Mashaeer by the department they had worked for during the Hajj. Then they were asked to evaluate in a four-point scale for all the services (whether or not provide by the department they had worked for during the pilgrimage season) showing their opinion whether they considered them sufficient or not sufficient for pilgrims in Makkah and Al-Mashaeer.

Table 3.7 shows these services sorted according to their sufficiency. The scale used were as follows: 4-points for Extremely Sufficient, 3-points for Sufficient, 2-points for Not Sufficient, and 1-point for Not sufficient at all. It can be seen that the first 18 types of services were considered sufficient as they have mean scores more than 3-points, and only 8 types of services were not considered sufficient. It can be concluded that the respondents were considered that most of the services provided for pilgrims in Makkah and Al-Mashaeer were sufficient.

Table 3.7 also shows the provision of services by the respondents departments. The scales used were: 2-points for providing the service, and 1-point for not providing that service. Twelve types of services had gained a score more than 1.5 which mean
that they were given by more than half of the respondents. The other 14 types were provided by less than half of the respondents as they gained less than 1.5 score.

It should be noted that the total number of questionnaires received was 297, and this number can be compared with the number of valid cases for each service, as some respondents didn’t answer all questions completely, and others answered only for services they provided.

**Table 3.7: Sufficiency and provision of services for the Pilgrims**

<table>
<thead>
<tr>
<th>Type of service</th>
<th>Sufficiency</th>
<th>Provision</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of cases</td>
<td>Mean Score</td>
</tr>
<tr>
<td>1. Security services</td>
<td>229</td>
<td>3.61</td>
</tr>
<tr>
<td>2. Safety and fire fighting services</td>
<td>222</td>
<td>3.54</td>
</tr>
<tr>
<td>3. Medical care service</td>
<td>243</td>
<td>3.52</td>
</tr>
<tr>
<td>4. Accommodation services</td>
<td>199</td>
<td>3.47</td>
</tr>
<tr>
<td>5. Administrative and management services</td>
<td>228</td>
<td>3.46</td>
</tr>
<tr>
<td>6. Emergency services</td>
<td>239</td>
<td>3.45</td>
</tr>
<tr>
<td>7. Transportation services</td>
<td>205</td>
<td>3.42</td>
</tr>
<tr>
<td>8. Educational and awareness services</td>
<td>234</td>
<td>3.41</td>
</tr>
<tr>
<td>9. Food and drink services</td>
<td>216</td>
<td>3.34</td>
</tr>
<tr>
<td>10. VIP hospitality services</td>
<td>175</td>
<td>3.33</td>
</tr>
<tr>
<td>11. Telephone services</td>
<td>216</td>
<td>3.3</td>
</tr>
<tr>
<td>12. Cleaning and maintenance services</td>
<td>190</td>
<td>3.28</td>
</tr>
<tr>
<td>13. Lost people guidance services</td>
<td>209</td>
<td>3.23</td>
</tr>
<tr>
<td>14. Selling a variety of goods</td>
<td>147</td>
<td>3.18</td>
</tr>
<tr>
<td>15. Public relation services</td>
<td>199</td>
<td>3.14</td>
</tr>
<tr>
<td>16. Post, Fax, and Telex services</td>
<td>194</td>
<td>3.13</td>
</tr>
<tr>
<td>17. Luggage keeping and safe deposit services</td>
<td>184</td>
<td>3.05</td>
</tr>
<tr>
<td>18. Lost property keeping services</td>
<td>182</td>
<td>3.01</td>
</tr>
<tr>
<td>19. Banking and currency exchange services</td>
<td>163</td>
<td>2.81</td>
</tr>
<tr>
<td>20. Booking or selling tickets</td>
<td>146</td>
<td>2.78</td>
</tr>
<tr>
<td>21. Elderly and handicapped special services</td>
<td>179</td>
<td>2.71</td>
</tr>
<tr>
<td>22. Hair cut and skin care</td>
<td>130</td>
<td>2.68</td>
</tr>
<tr>
<td>23. Laundry services</td>
<td>134</td>
<td>2.66</td>
</tr>
<tr>
<td>24. Social or recreational services</td>
<td>151</td>
<td>2.52</td>
</tr>
<tr>
<td>25. Holy and historical places induction</td>
<td>162</td>
<td>2.49</td>
</tr>
<tr>
<td>26. Nursery services</td>
<td>128</td>
<td>2.42</td>
</tr>
</tbody>
</table>
3.7 Evaluation of the concept of MSU

After a brief description of the proposed MSU, the respondents were given a list of different types of suggested MSUs and were asked to evaluate the feasibility of each one based on a scale of 4-points. The scale gives 4-points for 'Feasible very much', 3-points for 'Feasible', 2-points for 'Not feasible', and 1-point for 'Not feasible at all'.

Table 3.8 shows the accepted types of MSUs. Only services that gained mean scores of 3 points or more were considered accepted and were shown in that table, as they were in the area between 'Feasible' and 'Feasible very much'. These accepted MSUs were ranked in descending order according to their mean score. MSUs that had earned similar mean scores were then ranked according to their ascending Standard Deviations. Small values of Std. Deviation reflect a lower dispersion of opinions about that type of MSU. If some types were found to have equal mean scores and Std. Deviations, then they were ranked in descending order according to the number of valid cases.

MSUs that gained from 2 to less than 3-points were in the area between 'Feasible' and 'Not feasible' and were excluded due to the doubts about their feasibility. Services that gained less than 2 points would certainly excluded, as they were considered 'Not Feasible'. However, no proposed MSU scored less than 2 points, which shows that no service was completely rejected from the majority of the respondents. In addition, any MSU with Std. Deviation more than 1 would also be excluded because they had exceeded the range of 1-point difference. However, none of the services with a score between 3 and 4-points got a standard deviation more that 1-point difference, which reflects the general agreement about their feasibility. The excluded types of services were listed in Table 3.9 using the same procedure used for sorting accepted MSU in Table 3.8.

It should be mentioned that excluding these types of MSU in this study helped the researcher to concentrate his effort on developing and evaluating the most acceptable MSUs as perceived by the respondents. The researcher expects that when the selected MSUs should be implemented and proved successful, that would encourage others to consider developing the rest of the services as MSUs.
<table>
<thead>
<tr>
<th>MSU type</th>
<th>N Valid</th>
<th>N Missing*</th>
<th>Mean Score**</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Lost people guidance centre</td>
<td>283</td>
<td>14</td>
<td>3.67</td>
<td>0.51</td>
</tr>
<tr>
<td>2. Emergency centre</td>
<td>282</td>
<td>15</td>
<td>3.66</td>
<td>0.60</td>
</tr>
<tr>
<td>3. Educational and awareness centre</td>
<td>281</td>
<td>16</td>
<td>3.59</td>
<td>0.62</td>
</tr>
<tr>
<td>4. Water &amp; drinks selling or distributing lorry</td>
<td>278</td>
<td>19</td>
<td>3.56</td>
<td>0.58</td>
</tr>
<tr>
<td>5. Safety and fire fighting centre</td>
<td>272</td>
<td>25</td>
<td>3.56</td>
<td>0.69</td>
</tr>
<tr>
<td>6. Information centre</td>
<td>275</td>
<td>22</td>
<td>3.52</td>
<td>0.66</td>
</tr>
<tr>
<td>7. Medical care centre</td>
<td>285</td>
<td>12</td>
<td>3.51</td>
<td>0.72</td>
</tr>
<tr>
<td>8. Cafeteria or restaurant</td>
<td>268</td>
<td>29</td>
<td>3.50</td>
<td>0.67</td>
</tr>
<tr>
<td>9. Security and police centre</td>
<td>270</td>
<td>27</td>
<td>3.49</td>
<td>0.73</td>
</tr>
<tr>
<td>10. Food selling or distributing lorry</td>
<td>278</td>
<td>19</td>
<td>3.46</td>
<td>0.63</td>
</tr>
<tr>
<td>11. Traffic management centre</td>
<td>264</td>
<td>33</td>
<td>3.46</td>
<td>0.77</td>
</tr>
<tr>
<td>12. Heat stroke treatment</td>
<td>279</td>
<td>18</td>
<td>3.46</td>
<td>0.80</td>
</tr>
<tr>
<td>13. Public toilets</td>
<td>281</td>
<td>16</td>
<td>3.44</td>
<td>0.79</td>
</tr>
<tr>
<td>14. Environmental &amp; hygiene control office</td>
<td>269</td>
<td>28</td>
<td>3.42</td>
<td>0.75</td>
</tr>
<tr>
<td>15. Pilgrims public relations centre</td>
<td>261</td>
<td>36</td>
<td>3.40</td>
<td>0.65</td>
</tr>
<tr>
<td>16. Automatic bakery</td>
<td>272</td>
<td>25</td>
<td>3.38</td>
<td>0.81</td>
</tr>
<tr>
<td>17. Purifying and cooling water unit</td>
<td>270</td>
<td>27</td>
<td>3.37</td>
<td>0.77</td>
</tr>
<tr>
<td>18. Telephone cabins and communications centre</td>
<td>270</td>
<td>27</td>
<td>3.37</td>
<td>0.82</td>
</tr>
<tr>
<td>19. Luggage keeping and safe deposit centre</td>
<td>278</td>
<td>19</td>
<td>3.35</td>
<td>0.81</td>
</tr>
<tr>
<td>20. Translation services centre</td>
<td>260</td>
<td>37</td>
<td>3.35</td>
<td>0.81</td>
</tr>
<tr>
<td>21. Currency exchange office</td>
<td>267</td>
<td>30</td>
<td>3.34</td>
<td>0.68</td>
</tr>
<tr>
<td>22. Cleaning equipment and labour centre</td>
<td>257</td>
<td>40</td>
<td>3.33</td>
<td>0.80</td>
</tr>
<tr>
<td>23. Lost properties service centre</td>
<td>277</td>
<td>20</td>
<td>3.32</td>
<td>0.81</td>
</tr>
<tr>
<td>24. TV camera surveillance centre</td>
<td>247</td>
<td>50</td>
<td>3.32</td>
<td>0.81</td>
</tr>
<tr>
<td>25. Ice cubes machines</td>
<td>274</td>
<td>23</td>
<td>3.30</td>
<td>0.82</td>
</tr>
<tr>
<td>26. Field supervision office</td>
<td>265</td>
<td>32</td>
<td>3.29</td>
<td>0.72</td>
</tr>
<tr>
<td>27. Elderly and disabled people care centre</td>
<td>254</td>
<td>43</td>
<td>3.29</td>
<td>0.80</td>
</tr>
<tr>
<td>28. Garbage compressing unit</td>
<td>262</td>
<td>35</td>
<td>3.29</td>
<td>0.83</td>
</tr>
<tr>
<td>29. Central kitchen for camps</td>
<td>273</td>
<td>24</td>
<td>3.29</td>
<td>0.85</td>
</tr>
<tr>
<td>30. Dining hall</td>
<td>274</td>
<td>23</td>
<td>3.28</td>
<td>0.83</td>
</tr>
<tr>
<td>31. Transportation management office</td>
<td>256</td>
<td>41</td>
<td>3.27</td>
<td>0.76</td>
</tr>
<tr>
<td>32. Fast food wholesale factory</td>
<td>270</td>
<td>27</td>
<td>3.27</td>
<td>0.84</td>
</tr>
<tr>
<td>33. Post office and fax service centre</td>
<td>263</td>
<td>34</td>
<td>3.26</td>
<td>0.83</td>
</tr>
<tr>
<td>34. Public facilities maintenance centre</td>
<td>256</td>
<td>41</td>
<td>3.25</td>
<td>0.76</td>
</tr>
<tr>
<td>35. Field survey data collection office</td>
<td>259</td>
<td>38</td>
<td>3.24</td>
<td>0.74</td>
</tr>
<tr>
<td>36. General shops</td>
<td>267</td>
<td>30</td>
<td>3.22</td>
<td>0.80</td>
</tr>
<tr>
<td>37. Bus and vehicle workshop</td>
<td>264</td>
<td>33</td>
<td>3.22</td>
<td>0.85</td>
</tr>
<tr>
<td>38. Civilian security guard centre</td>
<td>252</td>
<td>45</td>
<td>3.19</td>
<td>0.87</td>
</tr>
<tr>
<td>39. Bank branch</td>
<td>268</td>
<td>29</td>
<td>3.17</td>
<td>0.79</td>
</tr>
<tr>
<td>40. Floodlight tower movable unit</td>
<td>252</td>
<td>45</td>
<td>3.14</td>
<td>0.88</td>
</tr>
<tr>
<td>41. Centre for governmental publicity</td>
<td>252</td>
<td>45</td>
<td>3.11</td>
<td>0.98</td>
</tr>
<tr>
<td>42. Central administrative centre</td>
<td>237</td>
<td>60</td>
<td>3.07</td>
<td>0.86</td>
</tr>
<tr>
<td>43. Supervisors accommodation</td>
<td>254</td>
<td>43</td>
<td>3.06</td>
<td>0.82</td>
</tr>
<tr>
<td>44. Tickets selling centre</td>
<td>235</td>
<td>62</td>
<td>3.04</td>
<td>0.89</td>
</tr>
</tbody>
</table>

* Missing values are: 'No response' and 'I don't know'
** 4: Feasible very much, 3: Feasible, 2: Not feasible, 1: Not feasible at all
### Table 3.9: Sorted Excluded Mobile Service Units

<table>
<thead>
<tr>
<th>MSU type</th>
<th>N Valid</th>
<th>N Missing*</th>
<th>Mean Score**</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>45. Nursery</td>
<td>239</td>
<td>58</td>
<td>2.94</td>
<td>0.88</td>
</tr>
<tr>
<td>46. Barber shop</td>
<td>263</td>
<td>34</td>
<td>2.94</td>
<td>0.90</td>
</tr>
<tr>
<td>47. Movable field laboratory</td>
<td>246</td>
<td>51</td>
<td>2.91</td>
<td>0.90</td>
</tr>
<tr>
<td>48. Sitting hall for pilgrims</td>
<td>254</td>
<td>43</td>
<td>2.91</td>
<td>0.96</td>
</tr>
<tr>
<td>49. VIP hospitality hall</td>
<td>239</td>
<td>58</td>
<td>2.86</td>
<td>0.96</td>
</tr>
<tr>
<td>50. Exhibition for the history of the Holy places</td>
<td>249</td>
<td>48</td>
<td>2.86</td>
<td>1.01</td>
</tr>
<tr>
<td>51. Travel agent office</td>
<td>262</td>
<td>35</td>
<td>2.82</td>
<td>0.90</td>
</tr>
<tr>
<td>52. Weather station</td>
<td>244</td>
<td>53</td>
<td>2.81</td>
<td>0.97</td>
</tr>
<tr>
<td>53. Commercial pay toilets</td>
<td>265</td>
<td>32</td>
<td>2.81</td>
<td>1.11</td>
</tr>
<tr>
<td>54. Internet services centre</td>
<td>231</td>
<td>66</td>
<td>2.66</td>
<td>1.00</td>
</tr>
<tr>
<td>55. Businessmen service centre</td>
<td>242</td>
<td>55</td>
<td>2.64</td>
<td>0.95</td>
</tr>
<tr>
<td>56. Laundry service centre</td>
<td>255</td>
<td>42</td>
<td>2.51</td>
<td>0.97</td>
</tr>
<tr>
<td>57. TV and radio hall</td>
<td>240</td>
<td>57</td>
<td>2.50</td>
<td>1.08</td>
</tr>
<tr>
<td>58. Meeting room</td>
<td>243</td>
<td>54</td>
<td>2.49</td>
<td>0.96</td>
</tr>
<tr>
<td>59. Social or recreational centre</td>
<td>232</td>
<td>65</td>
<td>2.28</td>
<td>1.03</td>
</tr>
</tbody>
</table>

* Missing values are: 'No response' and 'I don’t know'

** 4: Feasible very much, 3: Feasible, 2: Not feasible, 1: Not feasible at all

### 3.8 Hindering factors

A list of some factors that may hinder the implementation of MSUs in Makkah and Al-Mashaaer were given to the respondents. They had been asked to estimate the hindering level for each factor on a four-points scale, giving 4-points for ‘Extremely Hindering’, 3-points for ‘Hindering Slightly’, 2-points for ‘Relatively not hindering’, and 1-point for ‘Not Hindering at all’.

Table 3.10 shows these hindering factors sorted in descending order according to their mean scores. Factors gained equal mean scores were sorted in ascending order according to their Std. Deviation.
Table 3.10: Sorted Hindering Factors

<table>
<thead>
<tr>
<th>Hindering Factor</th>
<th>N</th>
<th>Mean Score*</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Traffic jams on car roads</td>
<td>287</td>
<td>2.87</td>
<td>1.15</td>
</tr>
<tr>
<td>2. The cost of manufacturing the MSU</td>
<td>279</td>
<td>2.8</td>
<td>1.35</td>
</tr>
<tr>
<td>3. The manufacturing process of the MSU</td>
<td>278</td>
<td>2.78</td>
<td>1.36</td>
</tr>
<tr>
<td>4. The space available to park the MSU</td>
<td>286</td>
<td>2.72</td>
<td>1.16</td>
</tr>
<tr>
<td>5. The network of exclusive bus roads</td>
<td>276</td>
<td>2.7</td>
<td>1.33</td>
</tr>
<tr>
<td>6. The time available to prepare the MSU</td>
<td>278</td>
<td>2.65</td>
<td>1.31</td>
</tr>
<tr>
<td>7. The time available to transport the MSU</td>
<td>279</td>
<td>2.64</td>
<td>1.3</td>
</tr>
<tr>
<td>8. Crowded pedestrian walkways</td>
<td>285</td>
<td>2.62</td>
<td>1.19</td>
</tr>
<tr>
<td>9. The existing available infrastructures</td>
<td>278</td>
<td>2.62</td>
<td>1.31</td>
</tr>
<tr>
<td>10. The storage process for the MSU</td>
<td>280</td>
<td>2.62</td>
<td>1.41</td>
</tr>
<tr>
<td>11. The maintenance process for the MSU</td>
<td>278</td>
<td>2.52</td>
<td>1.35</td>
</tr>
<tr>
<td>12. Existing road network</td>
<td>280</td>
<td>2.5</td>
<td>1.15</td>
</tr>
<tr>
<td>13. The existing administrative rolls</td>
<td>276</td>
<td>2.45</td>
<td>1.25</td>
</tr>
<tr>
<td>14. Existing available services</td>
<td>275</td>
<td>2.44</td>
<td>1.17</td>
</tr>
<tr>
<td>15. The operation process of the MSU</td>
<td>278</td>
<td>2.41</td>
<td>1.37</td>
</tr>
<tr>
<td>16. The way pilgrims will use the MSU</td>
<td>282</td>
<td>2.38</td>
<td>1.21</td>
</tr>
<tr>
<td>17. The existing way in providing services</td>
<td>272</td>
<td>2.37</td>
<td>1.13</td>
</tr>
<tr>
<td>18. The availability of manpower to operate MSU</td>
<td>280</td>
<td>2.31</td>
<td>1.34</td>
</tr>
</tbody>
</table>


3.9 Respondents' general opinion regarding the MSU

By the end of the questionnaire, as the respondents had gained good understanding of the proposed MSU and the possible hindering factors, while answering the forgoing questions, they were asked to give their general opinion regarding the concept of “Putting most services for pilgrims on lorries and trailers that are transported from one place to another before and after the movement of pilgrims through the roads assigned for the shuttle buses”. They were asked to give their opinion based on six-points scale, giving 6-points for 'Strongly agree', 5-points for 'Agree', 4-points for 'Slightly agree', 3-points for 'Slightly disagree', 2-points for 'Disagree', and 1-point for 'Strongly disagree'.

Table 3.11 shows the general opinion of the respondents about the concept of MSU. It can be seen that the majority of the respondents (83 %) were on favour of the concept, while only few (17 %) oppose the concept. The mean score for all opinions
is equal to (4.67 points) which falls in the region between 'Slightly agree' and 'Agree', with a Standard Deviation of 1.5 points. This result indicates the wide acceptance of the proposed MSU among the managers and supervisors responsible for providing the different types of services for pilgrims.

Table 3.11: Respondent's General Opinion in Putting Most Pilgrim's Services on Lorries and Trailers that Transported from One Place to Another

<table>
<thead>
<tr>
<th>Opinion</th>
<th>Frequency*</th>
<th>Percent*</th>
<th>Cumulative Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly agree</td>
<td>111</td>
<td>41.1</td>
<td>41.1</td>
</tr>
<tr>
<td>Agree</td>
<td>53</td>
<td>19.6</td>
<td>60.7</td>
</tr>
<tr>
<td>Slightly agree</td>
<td>61</td>
<td>22.6</td>
<td>83.3</td>
</tr>
<tr>
<td>Slightly disagree</td>
<td>10</td>
<td>3.7</td>
<td>87.0</td>
</tr>
<tr>
<td>Disagree</td>
<td>20</td>
<td>7.4</td>
<td>94.4</td>
</tr>
<tr>
<td>Strongly disagree</td>
<td>15</td>
<td>5.6</td>
<td>100.0</td>
</tr>
<tr>
<td>Total</td>
<td>270</td>
<td>100.0</td>
<td></td>
</tr>
<tr>
<td>Mean score**</td>
<td>4.67</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>1.50</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Excluded missing values: 'No response' and 'I don't know'

3.10 Closure

The methodology for the investigation of the proposed system of Mobile Service Units from the point views of service providers has been described and the outcome of the survey conducted was described. The profile of the respondents shows their wide experience in providing services for the Hajj and the different sectors were represented. The types of services suitable to be MSUs were identified and the factors affecting the implementation of the system were highlighted. The wide acceptance of service providers for the proposed system of MSUs encourages taking the research forward by investigating the possibility of physically making such a large system as will be discussed in the next chapter.
4.1 An Overview of Chapter Four

It is found from the investigation conducted in Chapter Three that the proposed system of MSUs is widely accepted by the Hajj service providers and 44 types of services were considered suitable to be mobile. Now, it is the aim of this chapter to investigate the technical possibility of making such a large system of MSUs, the resources for making them for the Hajj and how it can be integrated within the proposed Master plan for the Hajj. The contents of Chapter Four are organized as follows:

- **4.1 An Overview of Chapter Four**
- **4.2 The Methodology of the Investigation**
- **4.3 Review of Available Mobile Units for Different Services**
  - 4.3.1 Mobile Homes/Offices
  - 4.3.2 Mobile Command Centres
  - 4.3.3 Mobile Computer Services
  - 4.3.4 Mobile Shops
  - 4.3.5 Mobile Food Services
  - 4.3.6 Mobile Kitchens
  - 4.3.7 Mobile Bakeries
  - 4.3.8 Mobile Medical Units
  - 4.3.9 Mobile Labs
  - 4.3.10 Mobile Water Treatment
  - 4.3.11 Mobile Toilets and Showers
  - 4.3.12 Mobile Laundries
  - 4.3.12 Mobile Libraries
  - 4.3.12 Mobile Exhibitions
- **4.4 MSU Designs**
  - 4.4.1 Chassis and platforms for MSUs
4.2 The Methodology of the Investigation

The investigation of the possibility of making such a large-scale system of MSUs can be conducted through investigating the possibilities of making its components, i.e. the possibility of making MSUs for the different types of services needed, the availability of resources for economically making them and the possibility to integrate them within the urban forms of the Master plan for the cities of the Hajj.

An investigation for the mobile service units available in the international market was conducted throughout the websites of the companies specialized in designing and manufacturing mobile units for different services. A field visit was conducted during the Hajj 2001 (February and March 2001) to collect data and field observations related to the proposed system, to identify the resources for making MSUs for the Hajj, and to discuss design and related issues with officials and experts working in the Hajj.

4.3 Review of Available Mobile Units for Different Services

The need for mobility of different types of services and utilities are not uncommon for many industries as revealed from a search conducted through the internet. Some types of mobile units are presented below.
4.3.1 Mobile Homes/Offices

Many models of mobile homes are well developed for the leisure industry. They are available in different sizes, configurations, accessories and luxury options; which fit the needs of wide range of customers as can be seen from Figure 4.1. Such mobile homes can be easily furnished as an office for senior officials with accommodation facilities to account for 24-hr on-site supervision. Slide-out extensions are used in some models to add more space for furniture and circulation. Over sized caravan homes (Figure 4.1.e and f), with a body size of about (11.8 x 3.7 m), provide spacious internal space and have wheels for easy loading on trailers for transportation.

Figure 4.1: Different models of mobile homes are available on the international market which can be furnished as Mobile Offices with accommodation facilities.
4.3.2 Mobile Command Centres

The need of many law-enforcement bodies to closely supervise large operations or events has resulted in the development of many types of mobile command centres such as those shown in Figure 4.2. Small units can be used for fast deployments while larger units can be used when more officers and staff are needed onsite. Mobile communication facilities (Figure 4.2.a) provide communication on site. Slide-out extensions can also be used to increase the internal space (Figure 4.2.c and d).

4.3.3 Mobile Computer Services

Figure 4.3 shows a mobile computer training centre used to provide on-site computer training facilities. Such mobile computer centres can also be used during the Hajj to provide computing and Internet services for pilgrims. It also can be used for enquiry services once equipped with an external platform for customers.

Figure 4.2: Mobile Command Centres (Source: http://www.aksv.com, May 2003)

Figure 4.3: A mobile computer training centre (www.de-designs.com/Speciality_Vehicles/buses.htm, May 2003)
4.3.4 Mobile Shops

A wide range of mobile shops, such as those shown in Figure 4.4, can be used to sell groceries, essentials, and accessories. They are cheap to purchase or to make by individuals running their own business during the Hajj.

4.3.5 Mobile Food Services

Small mobile food vans are well known to the public as seen in many occasions. Figure 4.5 shows some larger food vans that are capable of serving larger numbers of customers with hot and cold meals and drinks. Some units are also equipped with ovens and grills for barbeques and grilled meals if needed.
4.3.6 Mobile Kitchens

Mobile kitchens produce large amount of meals within a short period of time in controlled and hygienic environments; an essential requirements for serving pilgrims in the Hajj. Figure 4.6 shows some types of mobile kitchens that can work as a single unit or in combination with other complementary units.

Figure 4.6: Mobile Kitchens produce a large amount of meals in a controlled and hygienic environment
4.3.7 Mobile Bakeries

The Mobile Bakery shown in Figure 4.7.a is built inside two 40 feet and one 20 feet trailer. It produces 2,000 buns/hr with four staff. The Mobile Bakery shown in Figure 4.7.b has a production capacity up to 4000 baked goods per hour. The Set-up of this mobile bakery in the field requires approximately one hour and dismantling can be achieved in approximately 20 minutes. The Mobile Field Bakery system shown in Figure 4.7.c produces over 4.5 tonne of bread per 20 hour shift, with a team of six operators. It comprises two expandable shelters, one providing a preparation facility and the other containing the baking oven.

(a)

(b)

(c)

Figure 4.7: Mobile bakeries produce large amounts of fresh bread on demand
4.3.8 Mobile Medical Units

Mobile medical facilities such as those shown in Figure 4.8.a permit the transportation of high technology equipment for on-site use, as well as the rapid processing of patients at a minimum cost on a share bases. Modular hospital solutions such as that shown in Figure 4.8.b, offer the flexibility to deliver health care in demanding conditions, wherever needed. It consists of a series of mobile units that are connected together to form a temporary field hospital ranging from a 10 unit hospital to a 22 unit layout. Smaller independent units, such as that shown in Figure 4.8.c, provide first aids and essential basic examinations and treatments.

Figure 4.8: Mobile medical units and Mobile field hospitals can provide a wide range of medical services
4.3.9 Mobile Labs

Mobile Labs such as the environmental lab trailer shown in Figure 4.9, can be used to ensure proper control of environmental contamination and for quality control of drinking water and food supplies. Such labs can be equipped with a variety of instruments that could serve multiple quality control tasks.

Figure 4.9: Mobile Lab (Source: http://www.ameri-can.com/pages/lab.htm, May 2003)

4.3.10 Mobile Water Treatment

Different types of mobile water treatment units such as those shown in Figure 4.10 are available on the international market. They can be tailored to provide the required water treatments and large production capacity. Such units can be used in the Hajj to provide purified chilled drinking water to groups of camps through local distribution pipe networks.

Figure 4.10: Different types of Mobile Water Treatments units
4.3.11 Mobile Toilets and Showers

Figure 4.11 shows examples of easily re-locatable restroom and shower trailers. The mobile restroom shown in Figure 4.11.b, with ground level accommodation for the physically impaired, accommodates 1,768 people over a four-hour event. The restroom shown in Figure 4.11.c accommodates 420 Men, 245 Women, and 34 physically impaired people per hour. The mobile trailer shown in Figure 4.11.d has 2 complete restrooms and 10 large showers.


4.3.12 Mobile Laundries

Mobile laundry services such as the unit shown in Figure 4.12 can be used to provide an important service for visitors of large events lasting for more than few days and helps to reduce water consumption compared with hand washing.

![Figure 4.12: A Mobile Laundry](source: www.ameri-can.com/pages/laundry.htm, May 3003)
4.3.13 Mobile Libraries

Mobile libraries and bookshops such as that shown in Figure 4.13 could provide an essential source for specialized books and references for the visitors of large events. Governmental organizations, that provide temporary libraries in their camps during the Hajj, would find such mobile libraries much easier to use.


4.3.14 Mobile Exhibitions

Many governmental and private organizations involved in the Hajj may find mobile exhibitions such as those shown in Figure 14 of particular benefit for informing the public of the services they provide and receiving their feedback.

![Figure 4.14: Mobile Exhibitions help publicity and obtaining feedback from the public](www.eventservicenet.co.uk/fpr10806.htm, May 2003)

4.4 MSU Designs

Some important aspects, related to designing MSUs, need to be highlighted in order to investigate the possibility of making specially designed MSUs. Some of these aspects are chassis and platforms, which affect the internal floor arrangement; suspensions that have particular advantages for specially designed MSUs, the possible forms and configurations of MSU enclosures and local standards for dimensions and weights of vehicles.

4.4.1 Chassis and platforms for MSUs

Different types of chassis for trailers can be used for MSUs platforms (Figure 4.15). Standard trailer chassis, such as that shown in Figure 4.15.a, are flat due to the placement of wheel assemblies completely under the platform which allows for a continuous flat internal floor. However, such platforms are relatively high to get onto for elderly customers. Therefore, such high platforms can be used for service that do not require much interaction with customers, or when customers can be served without a need to physically get onto the MSUs.

Single drop platform trailers, such as that shown in Figure 4.15.b, are also flat due to placing wheel assemblies completely under the platform, but are lower than standard trailers due to the use of smaller wheels, which make them easier to reach. Many types of MSUs can use this type of platform, which allows for easy access from both sides and the back. Double drops chassis, such as that shown in Figure 4.15.c, use normal wheels with double drop configuration, which give them the advantage of being very close to ground level such that few steps are needed for customers to reach the service. Using small wheels makes them even more accessible. However, MSUs using double drop chassis can only be accessed from the sides. Sliding axle trailers, such as that shown in Figure 4.15.d, can be used for easy loading and unloading of wheeled portable cabins and un-motorized MSUs. Being loaded on trailers, oversized cabins and MSUs can be legally transported on public roads using appropriate precautions. It should be noticed that since most MSUs are lightweight;
lighter chassis and wheel assemblies can be used, which reduces the cost of making specially designed MSUs.

![Images of different types of platforms and chassis for trailers](www.vivarek.ee/eng-drawing.php, May 2003)

**Figure 4.15: Some types of platforms and chassis for trailers**

### 4.4.2 Suspension system for specially designed MSUs

Among the different suspension systems available for trucks, trailers and buses that can be used for specially designed MSUs, air suspension systems such as those shown in Figure 4.16, have very useful characteristics. They provide a softer ride and greater protection from the effects of road shock on chassis, equipment, structure, driver and passengers. This allows for installing equipment in place inside an MSU without exposing them to excessive vibration during transportation, a vital requirement for delicate equipment. The most important characteristic for the specially designed MSUs, is the ability of some air suspension models to be deflated to lower the platform for easy loading, which is of great benefit to customers by making MSUs much easier to access.
The model shown in Figure 4.16.c is designed for buses, motor homes, and ambulances. The model shown in Figure 4.16.d is designed for both front and rear-engine school and commercial buses. The models shown in Figure 4.16.e and f, have the capability of being deflated to lower the platform for loading of goods and easy access of customers. The model shown in Figure 4.16.e has ride heights from 0.16 to 0.53 m, which provides low ground access when deflated and excellent ground clearance when lifted. This model has high-capacity air with low-operating pressures for rapid air-up and faster application and release cycles. The model shown in Figure 4.16.f can be used for both the pusher and tag position. The models shown in Figure 4.16.g and h, are steerable for easy manoeuvring. A tyre inflation system such as that shown in Figure 4.16.b, originally used for automatic tyre pressure maintenance, to minimize tyre wear and improve fuel mileage, could be investigated to be used to deflate tyres for further lowering the MSU, hence providing easier access for customers.

Figure 4.16: Some air suspension systems (Source: http://www.hendrickson-intl.com, May 2003)
4.4.3 MSUs designs and configurations

Generally speaking, many services that can be encapsulated in a small building can be fitted, in some way or another, in MSU as shown previously in section 4.3. Figure 4.17 shows more diagrams of possible designs and configurations for MSUs and Figure 4.18 shows photos of some readily available expandable structures that can be used for MSUs that require more space.

Ordinary high platform trailers, such as those shown in Figure 4.17.a, are so common that any quantity needed can be provided for the Hajj. Due to their high platform, they can be used for services that do not require customers to get into them such as administrative and supervision offices, production facilities and food supply trailers. However, these high platform trailers can be fitted, if needed, with low floor extensions, Figure 4.17, to enable easy access to the customer service zone. MSU trailers with double or triple drop chassis, such as that shown in Figure 4.17.b, have many advantages in terms of easier access for customers and more height available for work and storage. Foldable side walkways (Figure 4.17.c) allow customers to be served from the side of an MSU, allowing for additional external space for customers and easy queuing. Such arrangements can be used for services that deal with large number of customers with relatively short service time. They can be used for MSUs that sell or distribute ready-made food and drink, provide information and guidance services, inquiries or for publications distribution.

Additional internal space, for work, equipment or customers, can be gained using an expandable structural systems. Fold-down floors and fold-up roofs, such as those shown in Figure 4.17.d and Figure 4.18.a, can be used to increase the internal space three fold. Solid fold-up roofs (Figure 4.18.a) can be thermally insulated to provide good heat protection from the sun. Fabric roofs (Figure 4.18.b, c and d) are less thermally insulated but lighter and cheaper to make. Equipment will be placed and fixed in the solid central area (Figure 4.18.e) and movable furniture or equipment will be placed in the extension area. The deployment of the expandable structure can be achieved by means of built-in Electro-mechanical drive gear (Figure 4.18.a). The structure can be built using lightweight aluminium sandwich panel construction and can be connected by means of linking corridors (Figures 4.17.j, 4.18.c and f).
Fold-down extension floors with arched 'awning' roofs, such as those show in Figures 4.17.e and f and Figure 4.18.g, are faster to deploy. They also increase the internal space by up to 3 fold, but have less head clearances at the periphery, which may reduce the utilization of the additional space for some applications. An additional floor level (Figure 4.17.f) can be obtained by making use of the top of the main unit and equipping it with collapsible canopy. Figure 4.18.g shows a caravan with two tent-like motorised awnings that fold out to triple the floor area. The side walls descend to create two new areas and the facilities are in the solid central area.

(a)  
(b)  
(c)  
(d)  
(e)  
(f)  
(g)  
(h)  
(i)  
(j)  
(k)  
(l)

*Figure 4.17: Different possible designs and configurations for MSUs.*

Telescopic expandable structures such as those shown in Figure 4.18.i and j have solid sliding-out structures that provide better protection from the environment and faster deployment. The folding sides are light-weight and enables expanding and contracting shelter, as shown in Figure 4.18.j. They are made from 7.6 mm structural foam with a polyethylene film attached to each side and creased to allow folding. The end panels and doors are composite sandwich panels made with end grain balsa.
Van and trailer configuration (Figure 4.17.g) can be used for services that require frequent supply such as food services. The trailer can be used for preparation of food and serving customers while the van can be used as a cold storage unit. This moves separately to bring supplies. Demountable units, such as those show in Figures 4.17.h and 4.18.m, have the advantage of being placed very close to ground level to enable easy access for customers. They also have the advantage of being able to release the carrying truck or trailer so that it can be used to transport other units. Since these units have their own electromechanical lift aids, almost any truck or trailer can be used to transport them. It should be noted that considerable internal space saving can be achieved by designing MSU services facing outward (Figure 4.17.i), so that customers can queue and be served outside the unit. In this case, some temporary shading arrangements may be needed during the summer or rainy seasons.

For services that require very large space for customers, fixed or temporary tent structures (Figures 4.17.k and l) can be used for waiting and service areas, with MSUs carrying equipment being attached to them.

Figure 4.18: Some types of expandable structures that can be used for MSUs
Recycling buses presents great potential for making MSUs. Hundreds of old buses, used previously to transport pilgrims, go out-of-service every year (as will be discussed later). This forms cheap and abundant resources for making many types of MSUs. Figure 4.19 shows some modifications that can be made to buses to serve as MSUs. Figures 4.19.a and b show an out-of-service bus modified by one of bus companies working for the Hajj (Al-Magrabi bus company, Saudi Arabia), to be a multi purpose room for supervisors and bus drivers. They simply closed unwanted windows, installed heat insulation, covered the interior and provided an air-conditioning unit. Figures 4.19.c and d show the spacious interior of buses once seats are removed. Figure 4.19.d shows an external shaded platform that can be added to existing buses to allow customers to queue and be served from outside the bus. It is suggested that a foldable external platform is designed as a modular unit and manufactured in large quantities and offered to service providers to fix them to their modified buses. Figure 4.19.e shows a suggested modular unit that adds a low platform, which can be used as customer reception. This unit allows easy access for customers to the service area and uses the side bus door for access to the inside of the bus. Figure 4.19.f shows a suggested modular high platform that can be accessed from inside the bus. This additional space can be used as working space or a sleeping zone for workers. If more space is still needed, a modular upper platform (Figure 4.19.g) can be added, which can be deployed by electric or pneumatic actuators.

Figure 4.19: Out-of-service buses can be modified as MSUs
4.4.4 Saudi standards for trucks, trailers and buses

Figure 4.20.a shows the Saudi standards for the weights of trucks that need to be satisfied when designing special MSUs. MSUs are lighter than most loaded trucks due to the light equipment needed, which means that most MSUs satisfy weight regulations. If some MSUs are heavily loaded, multi axial configuration may be considered to distribute the load. Figure 4.20.b shows the vehicle classification scheme and the distances between axis. Table 4.1 shows the maximum dimensions for buses and trucks according to Saudi standards. It is worth mentioning that the lane width on the main roads of the master plan is increased from the standard 3.65 m to 4 m to account for 100% usage by buses and trucks (Beeah 1999). This extra lane width allows for designing MSUs wider than the standard if needed.

![Figure 4.20: The Saudi standards for trailers (Source: Ministry of Transportation, Saudi Arabia)](image)

![Table 4.1: Saudi standards for dimensions of buses and Truck (Source: Ministry of Transportation, Saudi Arabia)](table)

<table>
<thead>
<tr>
<th>Description</th>
<th>Maximum Dimension</th>
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<td>Length of a single truck or bus</td>
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<td>Length of a tractor and semi-trailer</td>
<td>18 m</td>
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<td>Length of a tractor and trailer</td>
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<tr>
<td>Length of a truck caring small cars</td>
<td>23 m</td>
</tr>
<tr>
<td>Width of any vehicle</td>
<td>2.6 m</td>
</tr>
<tr>
<td>Height of any vehicle</td>
<td>4.2 m</td>
</tr>
</tbody>
</table>
4.5 Investigation of Out-of-service Buses

During the field visit conducted during the Hajj 2001 (February and March 2001), an investigation of the buses used in the Hajj was held using the database of the Bus Union, Saudi Arabia, and by field visits to some bus companies. Two students assisted the researcher in photographing, measuring and drawing the layouts of the different types of buses. Data is used to identify the types and numbers of buses expected to be out-of-service in the next 18 years and in understanding their designs in order to convert them to MSUs.

Figure 4.21 shows some types of buses, used mainly to transport pilgrims during the Hajj, which are currently out-of-service or will be out-of-service in the next couple of years. Very old models have only one side door for passengers on the right side (drivers are always on the left-side of buses), an emergency door at the back and no door for the driver. Later models have two passengers doors on the right side and a driver’s door on the left. Most models have the first passenger door ahead of the front wheel and the second one between front and rear wheels. Some models have the second passenger door after the rear wheel. Most newer models are air-conditioned. Figure 4.22 shows the interiors of some buses and their air conditioning outlets.

Table 4.2 shows the number of buses, both out-of-service and in-service, mainly used for the Hajj, distributed according to their makers and year of manufacture. The number of seats for each type is indicated. Models with less than 5 buses were not presented in the table as they are too few to be considered in this research. It was found that the total number of large buses is 14,684 with an average of 50.08 seat/bus and the total number of medium sized buses is 397 with an average 31.6 seat/bus. Therefore, it can be concluded that large buses are dominant with an average capacity of 50 passengers. Medium sized buses are few when compared with large buses, but still can be considered for medium sized MSUs that require less floor area and more mobility. Table 4.3 shows the measured dimensions of some of these buses and the estimated internal floor areas. It is found that the average floor area for large sized buses is 25.2 m² and for medium sized buses is 9.9 m².
Figure 4.21: Types of buses that are currently out-of-service or soon to be out-of-service

Figure 4.22: Interiors of some buses that will go out-of-service in the next few years
Table 4.2: Number of buses available to Bus Companies working during the Hajj, their makers and models/year of manufacture

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<tr>
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<tr>
<td>Mitsubishi</td>
<td>92</td>
<td>21</td>
<td>75</td>
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Notes: - Out-of-service and in-service buses are included.
- Models with less than 5 buses were excluded from this table.
- The total number of large buses = 14684 with an average 50.08 seat/bus
- The total number of Medium size buses = 397 with an average 31.6 seat/bus.

Table 4.3: Dimensions of some buses and their internal floor areas

<table>
<thead>
<tr>
<th>Model</th>
<th>Capacity (passengers)</th>
<th>Width (m)</th>
<th>Length (m)</th>
<th>Floor Area* (Approximately)</th>
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Total 15081
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<td>5.8</td>
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<td>23</td>
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Average floor area for large buses (m²) = 25.2
Average floor area for medium buses (m²) = 9.9

* Note: Length and width were reduced by 0.15m to account for wall thickness.

Through a series of meetings with Bus Union officials and some bus companies after the Hajj 2001, the system of MSUs was introduced and the potential for recycling out-of-service buses was discussed. It was revealed that more than 4000 buses are already out of service and hundreds of buses go out-of-service every year (Figure 4.23). It was agreed that the 18 years service life for passengers buses, by Saudi regulations, is suitable from the safety and operational point of views. On the other hand, it was perceived that the recycled buses as MSUs would not require such high safety standards, as vehicles, since they would not transport passengers. Moreover they do not need to be in very good mechanical conditions due to the few, short trips needed. Therefore, the potential for recycling buses to be used as MSUs is highly convenient, as it opens new market for bus companies to sell their old buses and provides abundant and cheap resources for making MSUs for the required services to pilgrims. The rest of these out-of-service buses form an abundant spare parts resource for the reconditioned buses used as MSUs. Table 4.4 shows the number of new buses acquired by bus companies since 1984 and Table 4.5 shows the number of buses that will be out-of-service in the next 16 years. Figure 4.24 shows the expected accumulated number of out of service buses to 2019.

Figure 4.23: Out of service buses
Table 4.4: Number of new bus models purchased by Bus Companies Working at The Hajj
(Source: Najaba 2001)

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<td></td>
<td>49</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>56</td>
</tr>
<tr>
<td>SAPITCO</td>
<td>110</td>
<td>218</td>
<td>200</td>
<td>127</td>
<td>75</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
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<td>50</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Andalus</td>
<td>149</td>
<td>13</td>
<td>5</td>
<td>50</td>
<td>10</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>305</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>544</td>
</tr>
<tr>
<td>Arabiah</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td>Hafil</td>
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<td>916</td>
<td>300</td>
<td>350</td>
<td>7</td>
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<td>149</td>
<td>749</td>
<td>283</td>
<td>949</td>
<td>144</td>
<td>110</td>
<td>218</td>
<td>827</td>
<td>131</td>
<td>996</td>
<td>359</td>
<td>45</td>
<td>594</td>
<td>200</td>
<td>218</td>
<td>827</td>
<td>359</td>
<td>10552</td>
</tr>
</tbody>
</table>

Notes:  
- Only large and medium sized buses are included  
- Buses more than 18 years old will be out-of-service.

Table 4.5: Number of Buses that will be Out-Of-Service in the Next 16 Years

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>2910</td>
<td>313</td>
<td>333</td>
<td>373</td>
<td>160</td>
<td>177</td>
<td>213</td>
<td>304</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accumulated</td>
<td>2910</td>
<td>2910</td>
<td>2910</td>
<td>3223</td>
<td>3556</td>
<td>3929</td>
<td>4089</td>
<td>4266</td>
<td>4479</td>
<td>4783</td>
</tr>
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<table>
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<tr>
<th>Year</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>4932</td>
<td>5681</td>
<td>5964</td>
<td>6913</td>
<td>7057</td>
<td>7167</td>
<td>7385</td>
<td>8212</td>
<td>8343</td>
<td>9339</td>
</tr>
<tr>
<td>Accumulated</td>
<td>4932</td>
<td>5681</td>
<td>5964</td>
<td>6913</td>
<td>7057</td>
<td>7167</td>
<td>7385</td>
<td>8212</td>
<td>8343</td>
<td>9339</td>
</tr>
</tbody>
</table>

<table>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>359</td>
<td>45</td>
<td>594</td>
<td>1552</td>
<td>2479</td>
<td>307</td>
<td>356</td>
</tr>
<tr>
<td>Accumulated</td>
<td>9698</td>
<td>9743</td>
<td>10337</td>
<td>11889</td>
<td>14368</td>
<td>14675</td>
<td>15031</td>
</tr>
</tbody>
</table>

Figure 4.24: The expected accumulated number of out of service buses in the next 16 years
4.6 Integration of the system of MSUs within the Master Plan

It has been demonstrated in the previous sections that the large system of MSUs is physically viable. The following sections will investigate the possibility of integrating such a large system within the new master plan (section 4.6.3) for the cities of the Hajj.

4.6.1 Investigation of selected services provided during the Hajj

During the field visit conducted during the Hajj 2001, five students were assigned to collect field data for different services. The data collected includes service times, number of arrivals vs. time and floor plans of these services. The researcher and his assistant conducted field observations and photography for different types of services provided and special attention was given to any sort of mobile services. This data was collected in the four main pilgrimage areas during the Hajj. The photographs shown below were taken for some services during that visit. It should be noted that the photos were taken during off-peak times to avoid being stuck in the crowd. Although they do not represent the crowded nature of the Hajj, they give some idea of some services provided during the Hajj. In addition, it should be mentioned that an enormous number of photos taken during that visit (not shown) were used by the researcher to gauge the environment of the Hajj while developing the designs of the system of MSUs.

Figure 4.25.a and b show some parts of the tent city of Arafat, which is inhabited by pilgrims two days a year (Days 8 and 9 of the month of the Hajj) and uninhabited for the rest of the year. Figure 4.25.c and d show some parts of the tent city of Mina, which is inhabited on days 8, 10, 11, 12 and the 13th of the month of the Hajj. The tents and infrastructure in Mina are permanent although not inhabited the rest of the year. Figure 4.26 shows some food services provided during the Hajj. Figure 4.26.a and b show refrigerator trailers and trucks used mainly in Arafat to distribute cold water and drinks for free as gifts to pilgrims, and Figure 4.26.c and d show some food stores in Mina selling fast food, drinks and hot meals.
Figure 4.25: The tent cities of Arafat and Mina

Figure 4.26: Some food services provided during the Hajj

Figure 4.27 shows a typical compound for toilets and ablutions in Arafat and Muzdalifah where one side is used for female and the other side for male. Queuing is made in open air for safety and air hygiene reasons. Figure 4.28 shows some emergency and medical services. Figure 4.28.a shows the ambulance service
provided by the Red Crescent (An equivalent to the Red Cross), Figure 4.28.b shows a mobile hospital used by one of governmental bodies working during the Hajj. Figure 4.28.c shows mobile cabin camp for the Red Crescent, and Figure 4.28.d shows a compound for the Civil Defence. Figure 4.29 shows phone services. Figure 4.29.a shows a mobile transmissions tower for mobile phones and Figures 4.29.b and c shows pilgrims using telephone booths.

Figure 4.27: A compound for toilets and ablutions

(a)

(b)

(c)

(d)

Figure 4.28: Some emergency and medical services
4.6.2 Discussing the concept of MSUs with officials and service providers

Several meetings with officials and service providers were conducted in Riyadh, Makkah and Jeddah, Saudi Arabia, before, during and after the Hajj 2001. Preliminary designs for the proposed system of MSUs and their integration within the master plan were used as illustrations. These meetings highlighted many valuable issues, which were used to develop the system further both on a macroscopic and on a microscopic scale.

The latest developments for the concept of MSUs were presented to the Dean and colleagues at the CTHM Institute for Hajj Research, Umm Al-Qura University. They appreciated the developments and gave valuable comments and suggestions. Some economic aspects of the concept were also discussed with researchers at the department of Administrative and Humanitarian Research at the Institute.

The concept of using MSUs for medical services was discussed with officials responsible for providing medical services for a major governmental department working during the Hajj. They estimate that primary-care cases, mainly due to exhaustion, contribute 80% of the cases and can be treated onsite using simple equipments and medicines available at ambulances. The secondary-cases contribute 17% of the cases and patients need to be transported to the nearest available hospital.
The tertiary-cases contribute the remaining 3% of the cases and patients need to be transported to specialized hospitals. Therefore, they highly recommend using ambulances and small mobile medical-care units to treat the majority of patients onsite, while transporting the complicated cases to the nearest hospitals by ambulances as soon as possible. They also mentioned that mobile hospitals are good for emergencies in remote areas while ordinary hospitals are more convenient to operate and cost less to maintain.

In a meeting with Beeah, the architect of the new Master Plan, the integration of the proposed MSUs with the new master plan was discussed in details. It was concluded that the proposed system of MSUs could provide most of the services of the Master Plan and the proposed modifications to allow for MSUs parking (shown shortly) are possible. They also mentioned that spare parking spaces were made, for buses and services, which can be devoted to MSUs.

In a meeting with the head of planning studies at the Ministry of Transportation, the proposed system of MSUs was discussed from the planning point of view. He appreciated the concept and acknowledged the potential of the system to provide services for the Hajj. The integration of the proposed system of MSUs with the developed high-capacity transportation system of Shuttle Buses for the Hajj was discussed.

4.6.3 MSUs parking and their integration with the Master Plan

The concept of the Master plan is based on the excellent results achieved by the developed system of Exclusive Roads for Shuttle-Buses service discussed before in Chapter One. The Master Plan, shown in Figure 4.30, consists of six main loops, passing through the four cities of Makkah, Mina, Muzdalifah, and Arafat in addition to passing through Support zones between Arafat and Muzdalifah. Each loop serves four zones in each city and each zone accommodates 200,000 pilgrims, giving the total capacity of the master plan to host 4.8 million visitors/pilgrims (Beeah 1999).
Figure 4.30: The New Master Plan for the Cities of the Hajj (Source: Beeah 1999)

Figure 4.31. shows the city of Arafat according to the Master plan, its six loops and the four zones served by each loop. A distinct three digit numbering system is proposed for each zone to indicate (City number – Loop number – Zone number). The same numbers are giving to exits leading to their corresponding zones.
Figure 4.32.a shows Zone-432 (zone-2, at loop-3, at city-4) as a typical zone representing the main characteristics common to all zones. A central service road is dedicated to each zone to serve camps belonging to that zone. A central service area (shown by the white arrow in Figure 4.32.a), located at an intermediate distance between most camps, provides central public services shared by all camps in that zone. Private bus stops are located opposite to each camp as shown in Figures 4.32.b and c where pilgrims can easily reach their camps. A local service area is located near camps within short walking distance and can be easily accessible from the service road for supplies. Pedestrian walkways, separating camps and bus stops, allow access to other service areas.

Figure 4.32: Zone 432 as a Typical Zone in the Master Plan

Figure 4.33 shows some proposed modifications to bus stop arrangements in the master plan (shown in Figure 4.32 before), to introduce parking spaces for MSUs. Figure 4.33.a shows an arrangement for a parking space for one MSU between two
bus stops. This arrangement makes use of the space already used for bus manoeuvring and extends it a little to allow for MSU parking. In total, this arrangement will not significantly affect the number of bus stops nor change the length of the service road. Other advantages of this arrangement are the creation of a spacious plaza for pilgrims between buses and MSUs, allow accessing MSUs from the back and the right sides, and spreading MSUs evenly within the zone. Figure 4.33.b and c show arrangements for multiple MSUs, which enables parking related MSUs together or parking MSUs to serve multiple camps at the same time. Dual purpose parking, for buses and MSUs, can be used in tight locations and wherever additional bus stops are needed during transportation peaks and when additional MSUs are needed to meet peak demand for services. Most MSUs parking will be fitted with outlets for power, phone, Internet, water and sewage, dependent upon the type of MSUs allocated to each parking zone. Figure 4.34.a shows MSU parking in the central service zone and Figure 4.34.b shows local internal parking for MSUs.

![Figure 4.33](image-url) MSUs parking integrated with bus stops of the Master plan
4.6.4 MSU equivalents for the fixed services of the Master Plan

The Master plan has assigned space requirement for the main services at each zone, based on international, local and Hajj standards. It can be reasonably assumed that in order to estimate the MSU equivalents for these services, the total floor area for MSUs should be equivalent to those assigned by the Master plan, taking into consideration that MSUs use internal space more efficiently and use external spaces, which make the total MSUs area less than that required by the Master Plan.

Table 4.6 shows the floor areas for MSUs based on recycled buses, trailers and special designs. Different size categories are given to MSUs based on the total floor area they provide as shown in Table 4.7. Table 4.8 shows the services required by the master plan for each zone at Mina, their proposed MSU equivalents and the total number of MSUs required. The requirements for other cities are nearly the same with less requirements for Muzdalifah.
### Table 4.6: Approximate MSUs Floor Areas (m²) for different vehicle configurations

<table>
<thead>
<tr>
<th>Type of vehicle</th>
<th>Normal</th>
<th>Expandable One side</th>
<th>Expandable two sides</th>
<th>Expandable one side and roof</th>
<th>Expandable two sides and roof</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Bus</td>
<td>25</td>
<td>50</td>
<td>65</td>
<td>70</td>
<td>85</td>
</tr>
<tr>
<td>Medium Bus</td>
<td>20</td>
<td>40</td>
<td>50</td>
<td>55</td>
<td>65</td>
</tr>
<tr>
<td>Small Bus</td>
<td>10</td>
<td>20</td>
<td>25</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Single Truck</td>
<td>27</td>
<td>60</td>
<td>90</td>
<td>85</td>
<td>115</td>
</tr>
<tr>
<td>Long semi-trailer</td>
<td>35</td>
<td>75</td>
<td>115</td>
<td>110</td>
<td>150</td>
</tr>
<tr>
<td>Tractor and Trailer</td>
<td>40</td>
<td>80</td>
<td>120</td>
<td>120</td>
<td>160</td>
</tr>
</tbody>
</table>

### Table 4.7: Size Categories for MSUs based on Total Floor Area (m²) Provided

<table>
<thead>
<tr>
<th>SS</th>
<th>S</th>
<th>M</th>
<th>L</th>
<th>XL</th>
<th>XXL</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 to &lt;10</td>
<td>10 to &lt;20</td>
<td>20 to &lt;40</td>
<td>40 to &lt;80</td>
<td>80 to &lt;120</td>
<td>120 to 160</td>
</tr>
</tbody>
</table>

### Table 4.8: The Services Required by the Master Plan for Each Zone at Mina and Their Proposed MSU Equivalents and MSUs Batches

<table>
<thead>
<tr>
<th>MSU Service Type</th>
<th>Master Plan</th>
<th>MSUs Equivalents</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Quantity</td>
<td>Area (m²)</td>
</tr>
<tr>
<td>1. Lost people guidance centre</td>
<td>1</td>
<td>150</td>
</tr>
<tr>
<td>2. Emergency centre</td>
<td>1</td>
<td>200</td>
</tr>
<tr>
<td>3. Educational and awareness</td>
<td>1</td>
<td>150</td>
</tr>
<tr>
<td>4. Water &amp; drinks distributing lorry (water fountains)</td>
<td>4600</td>
<td>Place</td>
</tr>
<tr>
<td>5. Civil defence</td>
<td>1</td>
<td>400</td>
</tr>
<tr>
<td>6. Information centre</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>7. Health Centre</td>
<td>1</td>
<td>500</td>
</tr>
<tr>
<td>8. Cafeteria or restaurant</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>9. Security and police centre</td>
<td>1</td>
<td>400</td>
</tr>
<tr>
<td>10. Food selling or distributing lorry (Grocery shops)</td>
<td>240</td>
<td>10</td>
</tr>
<tr>
<td>11. Traffic management (Traffic police)</td>
<td>1</td>
<td>400</td>
</tr>
<tr>
<td>12. Heat stroke treatment</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>13. Public toilets (Toilet + Ablution)</td>
<td>4600</td>
<td>5.5</td>
</tr>
<tr>
<td>14. Environmental &amp; hygiene control</td>
<td>1</td>
<td>150</td>
</tr>
<tr>
<td>15. Pilgrims public relations</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>16. Automatic bakery</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>17. Cooling water machines</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>18. Telephone &amp; communications</td>
<td>1</td>
<td>120</td>
</tr>
<tr>
<td>19. Luggage keeping and safe deposit</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>20. Translation services centre</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>21. Currency exchange office</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>22. Cleaning labour centre</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>23. Lost properties service centre</td>
<td>-</td>
<td>-</td>
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<tr>
<td>24. TV surveillance centre</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>25. Ice cubes machines</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
4.7 Closure

The possibility of physically constructing such a large system of MSUs for the Hajj has been demonstrated. A review of the available mobile services on the international market has revealed that many services can be made mobile and used successfully for various applications. Most of these units can be used for the Hajj without much modification.

An investigation of various design aspects has demonstrated that a wide variety of MSUs designs and sizes are possible and can fit almost any application or services needed. Reconditioned and modified out-of-service buses have been found to be a very promising resource for constructing most of the MSUs needed for the Hajj due to the abundant resource of out-of-service buses and the possibility of adding more internal space using the proposed modular extensions. Modifications to bus parking has demonstrated the possibility to integrate MSUs parking within the Master plan. MSUs equivalents for the fixed services of the Master plan are defined.
CHAPTER FIVE
Modelling and Simulation of the System of Mobile Service Units (MSUs)

5.1 An overview of Chapter Five

Through the investigation conducted in Chapter 3, the proposed system of MSUs is now well understood from the point of view of service providers. In Chapter 4, it is shown to be physically achievable by demonstrating the different possible designs and resources for making them.

Now, in Chapter 5 and its complementary Chapter 6, the possibility of establishing this system in the Hajj, operating and controlling MSUs and their effects on transportation systems of the Hajj will be investigated. The methodology depends on modelling and simulation of the system of MSUs by computer. Therefore, this chapter reviews some modelling and simulation software to select the appropriate one for this study, then describes the development toward modelling and simulation of the main activities of the Hajj, demands for services and the movements of MSUs to fulfil these demands. The development and testing of the control for MSUs will be discussed in detail in Chapter 6. The contents of Chapter 5 are organized as follows:

5.1 An overview of Chapter Five 5-1
5.2 Investigation of modelling software 5-2
  5.2.1 The need for modelling and simulation of the system of MSUs 5-2
  5.2.2 Selection of modelling and simulation software 5-3
  5.2.3 Test modelling of the system of MSUs 5-5
5.3 Preliminary modelling of the system of MSUs 5-5
  5.3.1 Preliminary modelling of movements of MSUs and supply of services 5-7
  5.3.2 Preliminary control of the system of MSUs 5-8
  5.3.3 Preliminary simulation of the system of MSUs 5-8
  5.3.4 Simulation results for the preliminary model of the system of MSUs 5-9
5.4 The general Model of the system of MSUs
5.4.1 The components of the General Model
5.4.2 Modelling the Master Plan
5.4.3 Modelling the events' program of the Hajj and the variation of population vs. time
5.4.4 Modelling demand for services and MSUs supply
5.4.5 Modelling and simulation of MSUs and demands for services at zones
5.4.6 Modelling and simulation of Buses
5.4.7 Modelling and simulation of traffic conditions
Closure

5.2 Investigation of modelling software

The review of literature conducted in Chapter 2 revealed that no previous study has been conducted for modelling and simulation of such a system of Mobile Service Units for the services for the Hajj. Therefore, an investigation of appropriate software is conducted and a pilot test was made to test its capabilities before building the general model.

5.2.1 The need for modelling and simulation of the system of MSUs

It is quite difficult to establish the proposed system of MSUs directly into the Hajj without confirmation that it will work properly and provide the required level of services to pilgrims. General failure to provide enough services during the Hajj may results in severe consequences as it directly affects millions of people.

Simulation of the proposed system of MSUs allows testing the system for different proposals, assumptions, configurations, settings and scenarios without physical implementation during the Hajj. The experience gained from each simulation run helps to make improvements that can be tested again by simulation and so on until a satisfactory confidence is built for establishing the system for the Hajj.

Moreover, since simulation is conducted inside a computer, no physical MSUs and installations need be built, which saves money, effort and time. Through simulation the system of MSUs can be tested for the Hajj hundreds of times, which is almost impossible in reality as the Hajj occurs only once a year.
Proper modelling of the system of MSUs for the Hajj is needed prior to conducting simulation. The model should represent the main features of the events of the Hajj, the characteristics of the proposed MSUs and the characteristics of the new ‘Master Plan’ for the cities of the Hajj.

5.2.2 Selection of modelling and simulation software

There is a wide diversity of modelling and simulation software that can be trialed for suitability and use in this research such as SLAM II, SIMPROCESS, MATLAB and Simulink.

SLAM II and SLAMSYSTEM is simulation software that combines processes, events and continuous views into a model. The environment supports material handling devices, interactive execution and simulation project support. A simulation begins with a network model or flow diagram showing the flow of entities. A SLAM II network is made up of nodes on which processing is performed. Common functions include entering and leaving the system, reserving resources, starting and stopping flows, etc. Nodes are connected via ‘activities’ which define the routing of the entities. Time delays represent processing times, travel times, or waiting times. Entities proceeding from node to node have ‘attributes’ which determine their processing. (Drakos 1993).

SIMPROCESS is an object-oriented business process modelling, simulation and analysis tool written in Java and XML. It has hierarchical process modelling capability and allows the user to define the costs, capacity, usage and interdependencies associated with resources. It uses entities to represent physical or logical things that flow through the process model. Entities may be assigned attributes to define their characteristics. It uses connectors to link process or activities. It can provide an integrating framework for activity based costing and can model the causal relationships among resources, activities, and entities when assigning overhead costs. SIMPROCESS can measure the total time an entity spends traversing a process, the total number of entities that traverse a process and the percentage of time that a resource spends in each state. It can provide statistics for
measuring and analysing under-utilization or over-utilization of resources, activity cost, and evaluates alternative business decisions (CACI 2002).

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an environment where problems and solutions are expressed in familiar mathematical notation. Typical uses include: Maths and computation, algorithm development, modelling, simulation, prototyping, data analysis, exploration and visualization, scientific and engineering graphics and application development including graphical user interface building. MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. MATLAB features a family of application-specific solutions called toolboxes that allow application of specialized technology such as signal processing, control systems, neural networks, fuzzy logic and simulation (MathWorks/1, 2000).

Simulink is a software package for modelling, simulating, and analysing dynamical systems. It supports linear and nonlinear systems, modelled in continuous time, sampled time, or a hybrid of the two. Systems can have different parts that are sampled or updated at different rates. For modelling, Simulink provides a graphical user interface (GUI) for building models as block diagrams. Models are hierarchical, which permits building of models using both top-down and bottom-up approaches and provides insight into how a model is organized and how its parts interact. Simulation results and the effects of changing parameters can be seen while the simulation is running using oscilloscopes and other display blocks and users can immediately see what happens during "what if" exploration. MATLAB and Simulink are integrated which allows the user to simulate, analyse, and revise models in either environment (MathWorks/2, 2000).

MATLAB and Simulink were selected for modelling and simulation of the system of MSUs due to their characteristics described above. They have the functions and toolboxes needed for the model. These toolboxes can be customized and functions added. It can communicate and exchange data with other software and is widely available and well established at Loughborough University where this research conducted. Pilot tests confirmed the suitability of using SIMULINK and MATLAB for modelling the system of MSUs for this research.
5.2.3 Test modelling of the system of MSUs

In order to investigate the suitability of using MATLAB/SIMULINK for this study, a test modelling of the system is made for one site, MSUs-store, a road and a control centre (Figure 5.1). The event program is represented as variation of demand for service vs. time vs. location. A moving MSU is represented by a signal that moves from one subsystem to another. The MSU-signal is a matrix ‘MSU-matrix’ containing the main attributes for that MSU. Each subsystem extracts the relevant cell value from the ‘MSU-matrix’ signal as it enters the subsystem and modifies the relevant cell value as it leaves that subsystem. Preparation, transportation, and activity times were represented as variable delays introduced to the MSU-signal. MATLAB functions are used for writing control algorithms and data is stored as arrays accessible from all subsystems.

![Figure 5.1: The test model for the system of MSUs.](image)

5.3 Preliminary modelling of the system of MSUs

The test model is developed and extended as a preliminary model (Othman and Parkin 2002). The preliminary model consists of two main parts (Figure 5.2). The first part, on the left side of the figure, models the movement of visitors from one place to another and calculates the change of demand for services over time at each location. The second part, on the right side of the figure, models the movement of MSUs from one location to another in order to fulfil the expected and current demand for services at every location. Both parts of the model consist of several separate subsystems, which interact with each other and exchange data. These subsystems are designed to be independent so that they can be developed or replaced with the least interference on other subsystems.
The subsystem 'Event programs' (Figure 5.2) represents the time series of activities and events vs. their location and the number of expected participants/pilgrims. The subsystem 'Buses updated schedule' receives the requests for bus-trips for transporting participants to new locations and produces schedules for bus trips. Due to the limited capacity of road networks, not all bus-trip requests may be answered during peak times and will be shifted to some alternative time before or after the peak. Such shift is desirable to avoid many difficulties that are usually associated with peak times. 'Buses Back-up Schedule' keeps a record of the latest bus schedule and will be executed only if 'Buses updated schedule' fails. 'Buses Transportation Orders' executes bus-schedules and generates orders for buses to move. It may change the execution of bus-schedule slightly due to last minutes orders from the 'Control Centre'. The subsystem 'Buses Movements' generates traffic volumes on roads and time consumed by transportation before participants arrive at their destinations. The subsystem 'Buses Arriving at Site' accounts for the time needed for dispatching. Although buses are the main transportation mode during the Hajj, 'Other Transportation Modes' subsystem accounts for other transportation modes especially pedestrians. 'Population at Site' converts the number of buses, vehicles and pedestrians arriving at each site to population vs. time. 'Demand for Service' converts the population vs. time to demand vs. time taking into consideration the effects of event programs on the demand for particular services.

Figure 5.2: The preliminary model of the system of MSUs
5.3.1 Preliminary modelling of movements of MSUs and supply of services

General and special attributes can be ascribed to each type of MSU to describe their functions, characteristics, supplies, deliveries, inputs and outputs, in order to model them within the whole system. These attributes will also be important in making decisions about the most appropriate MSU to be sent to a particular location. Data is stored in a matrix form where rows represent MSUs and columns represent their attributes.

According to the expected/current 'Demand for Services' produced by subsystem-10 (Figure 5.2) and the measures for 'Customer Satisfaction' to be suggested by subsystem-22, the 'Control Centre' should authorise the 'MSUs Updated-Schedule' to respond and produces a schedule for MSUs indicating locations to be served vs. time. MSUs scheduling should takes into consideration traffic conditions to avoid peaks and give priority to bus movements by shifting MSUs movements before or after peaks. 'MSUs Back-up Schedule' keeps a record of the latest MSUs updated schedule to be executed in case of failure of the main schedule. The subsystem 'orders to move MSUs' executes the schedule by ordering MSUs to move to the next locations taking into consideration any last-minute orders from the 'Control Centre'. Some delay takes place prior to movement of MSUs, for serving the remaining customers and preparing MSUs to move, will be considered by the subsystem 'MSU preparations to move'. The 'Traffic Conditions' monitors 'Bus trips' and 'Other transportation modes' and calculates the expected transportation times at the different routes. The subsystem 'Traffic Conditions' also accounts for the time elapsed before the moving MSUs reach their destinations. Preparations times for MSUs for serving at their destinations are accounted for by Subsystem-17. Provided the resources for the service 'Services Resources' are available, MSUs should be ready to serve and their service capacities are added to their destinations by subsystem-19, 'MSU Supply at site'. MSUs supply and 'Fixed services supply' form the total services supply at the location. By the end of their service periods, MSUs are made available for the next job by subsystem-21 'MSU store'.
5.3.2 Preliminary control of the system of MSUs

The outputs of subsystem-10 ‘Demand for service’ (Figure 5.2) and subsystems-19 and 20 are fed to subsystem-22, which represents ‘Customer Satisfaction’. The availability of service when needed is an important factor in terms of customer satisfaction. If the demand for a service at a particular time exceeds the total supply of that service by a great margin, the result is long queues and long waiting times that reduce the level of customer satisfaction. On the other hand, if supply exceeds demand by a great margin, service providers satisfaction will be low as they provide services without enough customers, which increases the cost of their services. This in turn would reduce customer satisfaction as well due to the increased prices of services. In practice, questionnaires can be used to measure the level of customer satisfaction and compared with the actual amount of service provided, which can be considered for planning services for the next Hajj.

Therefore, the ultimate goal of the ‘Control Centre’ is to make the right balance between demand and supply of services at the different locations taking into considerations the limitations of MSUs availability, event programs and traffic conditions.

5.3.3 Preliminary simulation of the system of MSUs

The preliminary model operates in two modes: ‘Scheduling Mode’ and ‘Operational Mode’. In the Scheduling Mode, the model runs for the whole period and simulates the execution of the first part of the model which generates the expected demand for services according to the reservations for bus trips, shifted by a time delay for transportation and disembarking of participants. The generated expected demand vs. time will be fulfilled by scheduling MSUs to be sent to locations before they are actually needed by taking into account the time required for transportation and preparation. If traffic conditions are not suitable, MSUs will be scheduled for the first convenient delivery. The end time is determined when an MSU is no longer required at that location.

During Operational Mode, the model runs in real time. Bus trips are generated according to actual implementation of bus schedules with the latest modifications
updated by control. Actual traffic conditions are calculated from bus trips and actual transportation times are calculated from traffic conditions. The number of arrivals is added to the population and generates the actual demand for services. Meanwhile, MSUs are sent according to the schedule and if the control centre predicts severe diversion of actual service demand from the expected demand, it takes action by altering the execution of MSUs-schedule either by advancing or delaying an order to move MSUs. If extra service capacity is badly needed at some locations, the control centre sends MSUs from the reserve making the least amount of changes from the main MSUs schedule.

5.3.4 Simulation results for the preliminary model of the system of MSUs

During the preliminary modelling and simulation of the system, different control strategies and algorithms are tried (Othman and Parkin 2002) in order to develop the strategy that satisfies the needs of customers and the requirements of service providers. The algorithms are mainly conditional statements that represent the roles and conditions for requesting and releasing MSUs. Service Status (SS) is introduced to examine the quality of the algorithms. The value of SS is the difference between supply and demand for the service. Negative values for SS represent shortage of supply for the service. Therefore, one of the objectives of the control is to avoid negative values of SS whenever possible.

The first control strategy is based on online control, where SS is monitored and a MSU is requested whenever SS decreases below a specific value. One or more MSUs may be requested in advance to account for transportation time delay. Figure 5.3 shows some case studies for this strategy. As shown, the values of SS frequently become negative due to late request/arrival of MSUs at the beginning of the demand peak. Cases-a, b and c (Figure 5.3) introduced the need for another control objective to prevent the oscillation of requests and release of MSUs in an attempt to match the demand. Case-d (Figure 5.3) solved the oscillation problem by adding conditions for the minimum SS value before releasing MSUs. However, the problem of the shortage of supply at the beginning of the peak has not been solved despite the benefits of the modified. This is mainly due to the delay in the response of the system during MSU transportation.
The second control strategy is based on an off-line scheduling of MSUs before the event takes place. The expected demand vs. time is deduced from service providers’ experience or derived from events’ programs. During scheduling mode, the model runs using the expected demand making requests for MSUs whenever negative values of SS are detected. The time of the MSU-request minus the expected transportation and preparation times is recorded. When a positive value of SS exceeds the capacity of one MSU, an MSU is released and made available for another locations. Figure 5.4 shows the scheduled MSUs supply of service in order to satisfy the expected demand without negative SS values. It also shows the implementation of requesting the largest available MSUs first and the role of releasing MSUs on the bases of “first-come first-go” for equal opportunities to all MSUs. During operational mode, the model executes MSU schedules and sends MSUs at the specified times before the peak service occurs and releases surplus MSUs. This control strategy is found to be appropriate for controlling the system of MSUs as it accounts better for transportation and preparations delays. Figure 5.5 shows the demand for services at two locations at nearby pilgrimage areas (Mina and Arafat, which are 6 km apart) and their corresponding MSUs supply. The control algorithm responds to the variation in demand by discrete supply of MSUs both during scheduling and operational modes.

Figure 5.3 The trial of different control algorithms.
5.4 The General Model of the system of MSUs

5.4.1 The components of the General Model

The preliminary model gives satisfactory results, as shown beforehand, for one service and two locations (Othman and Parkin 2002). However, when it is extended to account for all types of services at all locations, the algorithm becomes too cumbersome to follow due to the intensive use of MATLAB text programming and the large number of loops needed to check all the locations and services. Therefore, when developing the general model of the system, it was decided to make more use
of the graphical programming capabilities of Simulink, whenever possible, with MATLAB text programming for special functions, if needed.

In the general model, many components of the preliminary model are developed as separate subsystems. The general model is designed as subsystems that contain sub-subsystems in a hierarchical order to organize the logic of modelling and permit modifications. Being modular, these subsystems can be modified individually or replaced by more sophisticated specialized software without affecting other subsystems as far as inputs and outputs are concerned. Figure 5.6 shows the main components of the general model in block diagram form and Figure 5.7 shows the Simulink model and its subsystems and most sub-subsystems. The remainder of this chapter will discuss these subsystems in more detail.

![Diagram](image)

*Figure 5.6: The main components of the general model for the system of MSUs*
Figure 5.7: The main subsystems of the General Model
5.4.2 Modelling the Master Plan

The new master plan for Al-Mashaeer (Beeah, 1999) shown previously in Figures 4.30 and 4.31 of Chapter 4, can be represented in the control centre in a simplified graphical form for the six loops as shown in Figure 5.8. Each loop passes through four pilgrimage zones at the four pilgrimage cities and has its own support area giving a total of 96 zones and 6 support zones. Zones are given distinct 3 digits number (city number, loop number, zone number) indicating their location. For instance, zone number 214 represents the 4th zone of loop no-1 (the first loop) at city no-2 (Mina).

The concept of the general model, shown in Figure 5.9, is derived from the proposed simplified representation of the master plan of Figure 5.8, and mainly uses the graphical programming capabilities of Simulink with MATLAB programming for any special functions needed. The concept is based on distributing the computational effort to subsystems representing the different zones, so that each zone does calculation for itself and sends the final result, MSU-request, to the ‘Control Centre’. The control centre is based in the support area for that loop. It receives requests from all zones and makes decisions about sending or returning MSUs to zones. This approach makes the logic more understandable and easier to develop, reflects the real graphical distribution, and distributes computational power among different zones. As a consequence, it also reduces the effect of the failure of any sub-system through the whole system.

Figure 5.9 shows the modelling of loop-1 and its four pilgrimage zones in the four cities using Simulink and MATLAB. Each zone accounts for 200,000 pilgrims and is represented by a subsystem. The ‘Zone’ subsystem calculates the accumulated number of arriving and departing pilgrims (mainly by buses) to estimate the current population in that zone. It also calculates the available MSUs service capacities, issues reports of the service status and makes ‘MSU-requests’ to the ‘Control Centre’, which will be discussed later in detail.

Since the six loops of the master plan are almost identical with small variations that can be considered in the definition of the characteristics of each zone, the general
model can be extended and duplicated five times to account for the remaining five loops. A supervisory control centre coordinates the six control centres at support areas for possible exchange of MSUs between them to cover peak demands at specific zones. However, for the purpose of this study, it is sufficient to study one loop as it is independent of other loops and represents them.

Figure 5.8: The representation of the Master Plan on the Control screen

Figure 5.9: The general model of the system of MSUs for loop-1.

5.4.3 Modelling the events’ program of the Hajj and the variation of population vs. time

The main events during the Hajj that of concern to this study are summarised in Figure 5.10. These main events are as follows:
1) Pilgrims arrive in Makkah from the early days of the month of the Hajj and the majority complete their arrival by Day-7.

2) About 45% of pilgrims prefer to go from Makkah to Mina to spend Day-8 in Mina (CTHMIHR/1). They start moving by midday of Day-7 and their peak movement is after sunrise on Day-8, until the completion of their arrival by midday of Day-8.

3) The other 55% of pilgrims prefer to go directly to Arafat from Makkah. They start their movement after midday of Day-8, reaching peak transfer between sunrise to the midday of Day-9 and continue to arrive until the evening of Day-9.

4) The 45% of pilgrims that spend Day-8 at Mina start to leave Mina to Arafat by the sunrise of Day-9 and complete their arrival before midday of Day-9. All pilgrims need to spend part of Day-9 in Arafat.

5) After sunset on Day-9, pilgrims start to move from Arafat to Muzdalifah creating a transportation peak that lasts until midnight.

6) After a short stay in Muzdalifah, some pilgrims start to move to Mina after midnight of Day-9. The rest spend the night at Muzdalifah and move to Mina after the sunrise of Day-10 and complete their arrival before the midday of Day-10. Most Pilgrims spend Day-10, 11 and 12 in Mina.

7) During their stay in Mina, some pilgrims go to Makkah to perform ‘Tawaf’, one of the programs of the Hajj, then return back to Mina.

8) The majority of pilgrims leave Mina for Makkah between midday of Day-12 to sunset of that day. The rest leave for Makkah after the midday of Day-13. By the end of this movement, all pilgrims will go back to Makkah to spend some time before going to another city, Madinah, or going back home.
The movement of pilgrims from one city to another during the Hajj produces a rapid change of population at these cities. Apart from Makkah, the other three cities are almost uninhabited except during the Hajj. This varies the population in each zone from zero to up to 200,000 pilgrims and back to zero within a short period. This variation of population is represented by the graph in the middle of Figure 5.10 for a typical zone from each city. In the case of Makkah, the population of residents is not shown in the curve since they have their own services and only the additional population due to arrival of pilgrims is considered.

The population in Figure 5.10 is measured in Pilgrim Units (PU), equivalent to 50 pilgrims. This unit is introduced to simplify and speed-up the simulation. It also represents the average number of passengers in a large bus and can be used for managerial purposes.

**Figure 5.10: The main events of the Hajj that are considered in the study**

The main events of the Hajj include:

1. Arrival to Makkah
2. From Makkah to Mina
3. From Makkah to Arafat
4. From Mina to Arafat
5. From Arafat to Muzdalifah
6. From Muzdalifah to Mina
7. To Makkah for Tawaf
8. Returning to Makkah

The population at the Four Pilgrimage Areas is measured in Pilgrim Units (PU) and varies significantly during the different days of the Hajj.
Events programs (subsystem 2.1, Figure 5.7) are translated to percentage variation of population vs. time at the different zones and are transferred to the workspace for the 7-day period. The output of the workspace is multiplied by a factor of 40 to represent PU. (100% = 200,000 pilgrims = 4000 PU) as shown in Figure 5.11.

![Event Program Diagram](image)

**Figure 5.11: Extracting the events programs of the Hajj from the workspace using subsystem no.2.1 'Event Program'**

Simulation is set to cover the period of seven days from day 7 to day 13 when most events of the Hajj occur. The simulation step is set to 0.025 hr (1.5 minutes) giving 40 simulation steps per hour with a total of 6720 simulation steps for the 7 day period. The simulation is set to ‘fixed step discrete’ in order to evaluate the system in periods rather than on a continuous time scale.

### 5.4.4 Modelling demand for services and MSUs supply

During the fieldwork conducted during the Hajj 2001, data was collected for selected services at different locations in terms of the variation of arrivals to each service vs. time and service times as a function of the number of arrivals. This data was used to estimate the capacity of services needed and the variation of demand with time. It was found that the demand for these services varies very much with time due to local sub-events, prayer times and the location of each service. Such fluctuations in demand for services for a given population would generate instability in the system if MSUs are going to be sent or released from a particular zone according to the actual demand for service.

Therefore, these details are replaced by the overall capacity for each service in terms of the number of units needed to serve the whole population of 4000 PU (200,000 pilgrims) at each zone. This is derived from the approach used by the Master Plan where space requirement is defined for each type of service (Beeah 1999). Table 4.8 of Chapter 4, showed the services required by the master plan and their MSUs
equivalents, where each service was matched with an appropriate size of MSUs, and a total number of MSUs is equivalent to the total area required, taking into consideration that MSUs are more efficient in utilizing internal space and external space will also be used. Therefore, each MSU should fulfill the needs of a given population covering all fluctuations in demand and it is unlikely that all of the population of a zone will require the same service at the same time. Hence, the 'service capacity' of an MSU is defined in this research by the population it can serve.

In order to simplify the complexity of graphs and speed-up simulation, the 44 types of services in Table 4.8, are grouped into 16 groups of similar service capacity and close ranks as presented in Table 5.1. It can be seen from the table that service capacity for MSUs ranges from 266.7 to 4000 PU, which is equivalent to 6.6% to 100% of maximum population of a zone respectively.

\[ \text{Table 5.1: The MSUs service groups and their service capacity} \]

<table>
<thead>
<tr>
<th>Service Group</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of services in the group (See Table 4.8)</td>
<td>1, 2, 3, 12, 14, 16, 17, 18</td>
<td>22, 23, 24, 25, 26, 27</td>
<td>4</td>
<td>5, 9, 11</td>
<td>6, 7</td>
<td>8</td>
<td>10</td>
<td>15, 19, 20, 21</td>
</tr>
<tr>
<td>Total no. of units per batch</td>
<td>8</td>
<td>6</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>10</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Total No. of Batches</td>
<td>2</td>
<td>2</td>
<td>9</td>
<td>3</td>
<td>4</td>
<td>10</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>Service Capacity per batch (PU)</td>
<td>2000</td>
<td>2000</td>
<td>444.4</td>
<td>1333.3</td>
<td>1000</td>
<td>400</td>
<td>500</td>
<td>4000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Service Group</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of services in the group (See Table 4.8)</td>
<td>13</td>
<td>28</td>
<td>29</td>
<td>30</td>
<td>31, 32, 34, 35, 37, 40, 41, 44</td>
<td>36</td>
<td>33, 38, 39, 42</td>
<td>43</td>
</tr>
<tr>
<td>Total no. of units per batch</td>
<td>9</td>
<td>2</td>
<td>4</td>
<td>10</td>
<td>8</td>
<td>2</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Total No. of Batches</td>
<td>15</td>
<td>12</td>
<td>10</td>
<td>10</td>
<td>2</td>
<td>13</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Service Capacity per batch (PU)</td>
<td>266.7</td>
<td>333.3</td>
<td>400</td>
<td>400</td>
<td>2000</td>
<td>307.7</td>
<td>4000</td>
<td>1000</td>
</tr>
</tbody>
</table>

It is worth mentioning that the exact number of MSUs and their sizes are not critical for this research at this stage, since the model should account for any variation in the number of MSUs. Also, the variation in service capacity between MSUs for the same service is not expected to be significant, therefore any MSU can be assumed to
be qualified to do the job without a need to specify a particular one. Very small units should be grouped together and considered as one unit in the simulation.

One service-group will be evaluated every simulation step (1.5 minutes) and all of the 16 service-groups will be re-evaluated every 24 minutes. The time for an evaluation cycle is sufficient to move an MSU from one zone to another, therefore, it is reasonable to assume that an MSU ordered to leave one zone at one evaluation cycle, will be serving in the next zone in the next evaluation cycle or soon after.

5.4.5 Modelling and simulation of MSUs and demands for services at zones

Inside each 'Zone' (Subsystem-1, Figure 5.7), the signal coming from the control centre is separated into its main signals using a 'Bus selector' block (Figure 5.12) and distributed to four subsystems representing 'MSUs in', 'MSUs out', 'Buses in' and 'Buses out' that model the arriving and departing MSUs and buses.

MSUs movements are represented by a [16x16] matrix signal. Each row corresponds to a particular zone and each column, a particular group of MSUs. The values inside the matrix represent the number of MSU batches. Inside each zone the subsystem-1.4 of Figure 5.7, 'MSUs in' uses a 'Direct Look up Table' block to extract the row corresponding to that zone only (Figure 5.13). This row represents all types of MSUs that have just reached that zone at the current simulation step. Since every
simulation step accounts for one group of MSUs at a time, the values in the row vector are zeros except for the cell corresponding to that service group which contain the number of batches if any.

**Figure 5.13: The subsystem 1.4 'MSUs in'**

A discrete time integrator block is used to calculate the total capacity of MSUs that entered that zone. The initial condition for integrator-blocks in Makkah zones is 4000, to represent that all of the MSUs (100%) are at Makkah at the beginning of the simulation. Other zones have no MSUs at beginning of simulation so their initial conditions are set to zeros. The 'MSUs-out' subsystem deals with 'MSU-out' signals and treats it similar to the 'MSUs-in' subsystem except that no 'IC' are set to Makkah zones. The output of the MSUs-out subsystem is the total number of MSUs that have already left that zone.

Population at a particular zone is estimated from the total number of loaded buses that entered that zone (the output of 'buses-in' subsystem) minus the total number of loaded buses left in that zone (the output of 'buses-out' subsystem). Other transportation means can be neglected as the new master plan depends mainly on large buses for transportation. The number of pedestrians entering or leaving that zone can be estimated using appropriate automated techniques such as infrared counters (Habibeh et.al 2003) and then added to the total population. However, for this research, the number of pedestrians is embedded within the number of buses arriving and leaving a zone.

The service capacity available at a zone depends on the number of existing MSUs which is the algebraic sum of 'MSUs-in' and 'MSUs-out'. The 'Service status' in a zone is the difference between the service capacity and population at that zone measured in PU (1 PU = 50 pilgrims). The MSU-request subsystem issues requests
for MSUs to the control centre based on population data, service capacity and service status.

5.4.6 Modelling and simulation of Buses

The subsystem ‘Buses to Zones’ (Subsystem 1.2, Figure 5.7) translates the variation of population vs. time to the number of buses needed to transport them from one zone to another. One subsystem ‘Buses-to-city’ is dedicated to each city (Figure 5.14).

![Diagram of Buses to zones](image)

Figure 5.14: The subsystem ‘Buses to zones’

‘Buses-to-city’ subsystem (Figure 5.15) subtracts the previous value of population stored in a ‘Unit Delay’ block from the current population fed from ‘events programs’. The initial conditions for the unit delay block is set to 4000 for Makkah zones since all pilgrims are in Makkah at the beginning of the simulation. A ‘Switch block’ is used to pass +ve values which represent an increase in population, otherwise, it passes zero to show that there is no increase in population. An ‘IC block’ sets the value to zero at the beginning of simulation. Since the population is in PU and 1 PU= 1 bus, then the output is the number of loaded buses going to a zone. The signal is duplicated four times for the four zones and combined into one signal using a ‘Mux block’.

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5 - 22
A subsystem ‘Buses-Limiter’ (Figure 5.16) is added to subsystem ‘Buses-to-zones’ to prevent sending buses with more than the capacity of the loop of 75 LV/SS. The input of the subsystem ‘Buses-limiter’ is the number of buses to be sent. If that number is below the maximum allowable buses per simulation step, then it is allowed to pass through the ‘Switch’ block. If it is equal or greater than the maximum value, a ‘Saturation’ block limits the number of buses to be sent in the current simulation step and records the number of remaining buses in a ‘Unit-Delay’ block to be added to buses to be sent in the next simulation step. This limitation of bus trips to within the capacity of the road network assures smooth traffic flow and can be achieved by a proposed online bus reservation system.

‘Buses from zones’ subsystems are almost the same as ‘Buses-to-zones’ subsystems except that the current value of population is subtracted from the previous population to account for the decrease in population. No initial conditions are set for Makkah zones.

Buses are represented by a signal of [16x1] matrix, each row corresponds to a particular zone and a cell value states the number of buses going to or leaving that zone. A ‘direct Look-Up Table’ block (Figure 5.17) is used to extract the relevant row for each zone depending on zone index. The total buses-in is calculated using a
‘Discrete-Time Integrator’ block. For Makkah zones, the initial condition for the ‘Integrator block’ is set to 4000 PU since all pilgrims are in Makkah at the beginning of the simulation.

![Image of 'Buses In' subsystem]

**Figure 5.17: Insid ‘Buses in’ subsystem**

### 5.4.7 Modelling and simulation of traffic conditions

Initially, the road networks of the master plan were modelled as sections of roads connecting junctions, giving a unique number to each junction and each road section is defined by the two junctions it connects. The length, number of lanes and road type for these road sections are listed in Road-networks database. In order to model the road network, the current and expected traffic volumes and conditions are to be calculated for each road section according to the actual bus and MSU movements and their schedules and is updated in the road database. A route, defined by a series of junctions, will be selected according to traffic conditions on all route. A ‘route selector’ will specify the main route and an alternative one. In reality, more sophisticated simulation software should be used for online calculation of the maximum number of additional vehicles that can be allowed to enter the road network, together with the expected travel time and in accordance with traffic conditions on each route, to assist ‘route selector’ subsystem.

However, due to the relatively short distances between the four pilgrimage cities, it was found that most road sections are too short to be considered as a single entity and hence the excess computational efforts are not justified for this study. Therefore, another approach is sought. Since each loop in the master plan serves the same zones in the four cities and is independent of other loops, it is reasonable to model each loop separately. Moreover, attention is focused on the traffic volume at the main road rather than the local roads as will be describe in the following section.
The simulation of traffic conditions for the master plan is simplified by setting the objective of control to assure that the traffic in the main road should not exceed the traffic volume capacity of 750 large vehicle (LV)/lane/hr, even though it could reach 815 LV/lane/hr for a short time (Othman, 2002). The 750 LV/hr is equivalent to 75 LV for every simulation step (4 lanes x 750 LV/hr / 40 SS/hr). ‘Traffic-volume’ subsystem (Subsystem 2.3, Figure 5.4), calculates the total number of vehicles (buses and MSUs) on the road at every simulation step. The output of the subsystem is provided with a ‘switch’ block to turn-On or Off the effect of traffic conditions for different simulation scenarios (Figure 5.18).

![Traffic Volume Diagram](image)

**Figure 5.18: A switch block is used to alter the effects of traffic conditions**

Inside the ‘Traffic-volume’ subsystem (Figure 5.19), the last number of buses sent to zones is stored in a ‘Unit delay’ block and is summed by a MATLAB function ‘Total-Buses’. The number of MSU-batches sent to zones is multiplied by the number of units per batch extracted from the subsystem ‘MSU-Batches-size’ to obtain the total number of MSUs on the road. The total number of MSUs on the road in the last simulation step that was stored in the ‘Unit delay’ block is summed by the function ‘Total-MSUs’. The total number of vehicles is the summation of the number of buses and MSUs. ‘IC’ is used to state that no vehicles are on the road at the beginning of simulation.

![Inside Traffic-volume subsystem Diagram](image)

**Figure 5.19: Inside the ‘Traffic-volume’ subsystem**
5.16 Closure

The need to model and simulate the system of MSUs is justified and appropriate software (MATLAB/Simulink) is selected and used for modelling the system. Different versions of the model have been evaluated before arriving at a satisfactory representation of the system. The modelling of the system as a whole is made by modelling each of its main components, i.e. the master plan for the cities of the Hajj, the events programme of the Hajj, demands for services, MSUs for supply of services, MSUs availability, bus and MSU movements and traffic conditions. The approach for managing/controlling these MSUs in order to satisfy the variable needs for services at different locations will be described in the following, Chapter 6.
6.1 An overview of Chapter Six

After developing a general model for the system of MSUs, as described in Chapter 5, our attention in this chapter is turned to describing the approach for managing these MSUs. The possibility of setting a proper schedule for MSUs to provide services at the different locations is investigated and the development of the control for the system of MSUs for an active response of MSUs to the variable demand for services is described in detail. The contents of Chapter Six are organized as follows:

6.1 An overview of Chapter Six 6-1
6.2 Scheduling MSUs 6-2
   6.2.1 MSUs scheduling category 6-2
   6.2.2 MSUs serving jobs 6-4
   6.2.3 Scheduling MSUs for serving jobs 6-5
   6.2.4 Selection of the scheduling method for MSUs 6-8
   6.2.5 Measuring scheduling efficiency for MSUs 6-9
6.3 Controlling the system of MSUs 6-10
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6.4 Developing Fuzzy logic controllers (FLC) for the system of MSUs 6-23
   6.4.1 Version 1-1 6-24
   6.4.2 The FLC 'Approval' 6-25
   6.4.3 Simulation results for Version 1-1 of the General Model 6-26
   6.4.4 Versions 2 to 5 of the General Model 6-27
6.2 Scheduling MSUs

The demands for services at different locations can be satisfied by proper management of movements of MSUs to fulfil those needs. This can be achieved by setting a "good" schedule for all MSUs before the Hajj and executing it properly without much change unless necessary.

6.2.1 MSUs scheduling category

Scheduling models can be divided into different categories such as: single machine, flow shop, parallel machines, job shop, open shop, assembly line, etc. (Sule, 1997). The nearest scheduling category to the case of scheduling MSUs is parallel machines. In parallel machines (Figure 6.1), a number of identical machines are available, and jobs can be processed on any of them (Sule 1997).
However, two major differences between scheduling parallel machines (Figure 6.1) and scheduling MSUs (Figure 6.2) can be seen. First, parallel machines are usually fixed and jobs are transported to machines, while MSUs (machines) are moving to the fixed locations of serving jobs. Second, the start and end times of processing jobs in parallel machines can be manipulated to satisfy scheduling objectives, which makes the scheduling algorithm focus on scheduling jobs to machines. On the other hand, serving jobs for MSUs have fixed start and end times and cannot be manipulated without heavy penalties. This makes the MSUs scheduling algorithm focus on scheduling MSUs for serving jobs. Table 6.1 describes some of similarities and differences between Parallel machines and MSUs.
Table 6.1: Comparison between Parallel processing and MSUs

<table>
<thead>
<tr>
<th>Parallel Processing</th>
<th>MSUs</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Jobs can be processed by any one of identical machines</td>
<td>• Serving jobs can be satisfied by any one of almost identical MSUs</td>
</tr>
<tr>
<td>• Jobs are usually transported to machines</td>
<td>• MSUs are transported to locations for serving jobs</td>
</tr>
<tr>
<td>• Jobs can have different start time, possibly due times and fixed processing time</td>
<td>• Jobs have fixed Start, Duration and End time.</td>
</tr>
<tr>
<td>• Jobs may have dependencies</td>
<td>• No dependencies between jobs</td>
</tr>
<tr>
<td>• Sequence of jobs usually changed. Due date need to be satisfied</td>
<td>• Sequence of jobs cannot be changed due to fixed ST</td>
</tr>
<tr>
<td>• Any job could be assigned to any machine</td>
<td>• Any MSUs could be assigned to any serving job</td>
</tr>
</tbody>
</table>

6.2.2 MSUs serving jobs

The serving jobs for MSUs can be represented by rectangles with height (or width) equal to the service capacity of MSUs and their length equal to durations of those jobs (Figure 6.3). The start and end times for jobs are the two ends of these rectangles. Early and late start and end times are the deviation of the two ends of the rectangles from start and end times.

![Figure 6.3: MSU serving job representation](image)

The demand for services at a particular zone or location can be represented by a graph of demand in PU vs. time for that zone. For MSUs of almost equal service capacity; two roles can be applied: a) "First MSU come first released" and b) "First
MSU come last released”. For MSUs of different service capacities; four roles can be applied: c) “Larger MSUs come first released last”, d) “Larger MSUs come first, released first”, e) “Smaller MSUs come first, released last” and f) “Smaller MSUs come first, released first”. Serving jobs using the first four roles are presented in Figure 6.4.

![Diagram](image)

Figure 6.4: Demand for service and MSU serving jobs.
a) “First MSU come first released”, b) “First MSU come last released”, c) “Larger MSUs come first released last” and d) “Larger MSUs come first, released first”

6.2.3 Scheduling MSUs for serving jobs

In the preliminary model, mentioned beforehand in Chapter 5, the scheduling of MSUs is performed by running the simulation using the expected population at different locations in order to assign a schedule for each MSU. The approach is to consider an instant response of available MSUs to serve any over demand, then to subtract the travel and preparation times from the current simulation time to account for the time for sending that MSU i.e. the start time of the job. The finish time for that job is the time when that MSU is assigned another job. The selection is based on the first MSU sent to a zone, which will be the first to go out from that zone. This will give almost equal working times for each MSU to avoid that the last arriving unit leaves first without enough working time.
In the general model, scheduling multiple MSUs for serving jobs at different locations can be achieved as demonstrated in Figure 6.4 using the following algorithm:

1- Generate serving jobs from the expected population curve using the rule “First MSU come first released”, assign start and end times for each job and give it a unique identity number. MSUs of the same service type have almost equal service capacity. Small MSUs are grouped together and considered as one average MSU.

2- Sort jobs according to start times (ST) in ascending order to give priorities for starting jobs on time, then by end times (ET) in ascending order to give priority to jobs that release MSUs earlier.

3- Apply an appropriate scheduling method to assign MSU(i) to serving jobs(j) that satisfies scheduling objectives.

The left part of Figure 6.5 shows the curves for demand for service at four different zones and the corresponding MSUs serving jobs, which satisfies that demand generated from step-1 of the algorithm. The middle and right parts of the figure show jobs sorted for each zone and for all four zones by apply step-2. The lower part of the figure shows the serving jobs assigned to the required number of MSUs from step-3.
Figure 6.5: Demand for service, generation of serving jobs and MSUs assigned to serving jobs.
6.2.4 Selection of the scheduling method for MSUs

Scheduling methods are tools that allow production and other systems to run efficiently. Different scheduling methods are already available and can be used with slight modifications for scheduling MSUs. Brucker (1995) discussed polynomial algorithms, enumerative procedures based on branch & bound concepts, dynamic programming, local search algorithms, classical scheduling algorithms for solving parallel machine problems and discussed problems with identical, uniform and unrelated parallel machines. Sule (1997) applied practical heuristic approaches based on simple algebra, instead of concentrating on highly complex mathematical techniques, to planning and prioritising resources in both the manufacturing and service industries.

Evolutionary Computation is a generic term for computational methods that used models of biological evolutionary process for the solution of complex engineering problems. The techniques of Evolutionary Computation have in common the emulation of the natural evolution of individual structures through processes inspired from natural selection and reproduction. These processes depend on the "fitness" of the individuals to survive and reproduce in a hostile environment. Evolution can be viewed as an "optimisation" process that can be emulated by a computer. Evolutionary Computation is essentially a stochastic search technique with remarkable abilities for searching for global solutions (King 1999).

Genetic Algorithms are the most popular Evolutionary Algorithm. It is used for solving complex engineering problems and used successfully for scheduling problems (Kis, 2003; Keung et al 2003; Wang, 2003 and Cochran et al 2003). The Genetic Algorithm has a high potential to be used for scheduling MSUs due to its capability in solving multi-dimension scheduling problems. Scheduling MSUs for serving many jobs at different locations needs to consider many factors simultaneously to reach the appropriate schedule that satisfies scheduling objectives with high scheduling efficiency. Some of the factors that affect MSUs schedules are the availability of MSUs, traffic conditions and service status at each zone. MSUs scheduling objectives are: maximizing the number of satisfied serving jobs, equal opportunities for all MSUs, minimizing the number of MSUs needed, maximizing
the utilization of MSUs, etc. The following stages must be considered in design and use of a Genetic Algorithm:

1) The creation of the initial population ‘Initialisation’,
2) the representation-mapping of the candidate solutions,
3) the evaluation of the fitness of every candidate solution,
4) the implementation of the exploration operators-recombination and mutation,
5) the selection of the parents for reproduction of the offspring-selection and
6) the choice of the parameters of the Genetic Algorithm (King 1999).

6.2.5 Measuring scheduling efficiency for MSUs

Scheduling efficiency can be measured through various indices. Two of the most popular are minimization of time required to complete all jobs (makespan) and minimization of penalty for completing jobs early or after the due dates (Sule 1997). Since MSUs serving jobs have fixed start and end times, the makespan is fixed and cannot be manipulated. The scheduling of MSUs should aim to minimize the penalty for completing jobs early or after the due dates. If an MSU arrives long before it is needed an ‘Early Start penalty’ will be considered to reflect the loss of service capacity that was not used. If it arrives late, after it is needed, a ‘Late Start penalty’ will be considered to reflect the un-served customers due to the shortage of service provided and the lost income opportunity for service providers. The ‘Late Start penalty’ should be given a higher weighting factor than ‘Early Start penalty’ to give more weight to customers.

If an MSU is forced to leave a zone, where it is still needed, to serve somewhere else where it is needed more, an ‘Early End penalty’ will be considered to reflect the un-served customers due to the shortage in services provided in the previous zone. On the other hand, if it is released long after it is not needed any more in that zone, for any reason, while needed in other zones, a ‘Late End penalty’ will be considered to reflect the lost income opportunity. The ‘Early End penalty’ should be given a
higher weighting factor than the ‘Late End penalty’ to give more attention to customers.

Equal opportunities for MSUs can be achieved by assigning almost equal ‘Total Working Time’ (TWT) for all MSU and close values for ‘Average Working Time’ (AWT) to each MSU in order to evenly distributed serving loads.

6.3 Controlling the system of MSUs

In the previous section, an approach to scheduling MSUs is described and can be used for preliminary and backup schedules for MSUs. However, due to the dynamic nature of the Hajj, the patterns of movements of visitors are continuously changing (as shown before in fig 5.10) and hence the demands for services are not likely to be close to forecasts and the schedule needs to be updated frequently to reflect these changes. Therefore, a fixed schedule for MSUs may not be the best alternative to achieve the objectives of higher MSUs utilization and higher customer satisfaction.

The concept of Just-In-Time (JIT) is widely used in modern industry (Mefford, 1993; Cunasekaran, 1999 and Machuca, 2002). JIT provides supplies at the right time to the right place just before they are needed, which reduces the cost of inventory, saves storage space and is a better match to variable market demand.

In order to reduce the total number of MSUs and increase their profitability without a noticeable reduction in service supply, the concept of JIT will be applied to the system of MSUs, with some modifications, by sending the right MSU to the right zone (location) at the right time just before it is actually needed. This can be achieved by frequent updating of MSUs schedules and online orders to relevant MSUs to execute the next jobs only. Enough time will be given for preparations and transportation of MSUs. Operators can access the latest updated schedule for the remaining jobs for their unit for their own convenience and as a backup schedule. The availability of different communication technologies (Internet, internet mobiles, mobile phones, pagers, faxes, wireless sets, etc), allows for efficient online orders to MSUs operators to start new serving jobs just-in-time.
6.3.1 The concept of control

There are different forms of control; the closest to the case for controlling MSUs is the closed-loop control system. The term ‘closed-loop control system’ is used for a system with feedback of the controlled variable so that the input to the system can be modified in order to achieve the required output (Bolton, 1998). Figure 6.6 represents the basic elements of a closed-loop control system.

![Figure 6.6: The basic elements of a closed-loop control system](image)

Bolton (1998) mentioned that a closed-loop control system has five basic elements: comparison, control correction, feedback of measured value and the process of which a variable is being controlled.

1. The comparison element compares the value required with that actually happening and the error signal becomes the input to the control element. The + and - signs on the inputs to this element are the indicate that the set value has the feedback subtracted from it.

2. The control element determines the action to be taken as a result of the input to the system.

3. The correction element has an input from the controller and gives an output of some action designed to change the variable being controlled.

4. There is a measurement element which measure the value of the variable actually occurring and feed back the value for comparison with the set value.

5. The process of which a variable is being controlled.

In the case of the system of MSUs, the process to be controlled is the supply of service of a particular type at a particular zone, the measurement is the status of that
service provided, the *set value* is the acceptable or planned status for service to be provided and the *error* is the deviation of current status for that service from the planned status. The *control* is the command centre that makes decisions regarding the reported situations and issues orders accordingly to MSUs operators. The *correction* is returning unneeded or least needed MSUs and sending MSUs to needy zones to start new serving jobs.

The following will describe the search and development of a proper control for the system of MSUs.

### 6.3.2 Control by conditional statements programming

In the preliminary model, described beforehand in Chapter 5, the control of MSUs is based on ordinary programming using conditional statements (If-conditions-Then statements). The program executes listed control statements according to the occurrence of the relevant conditions. This control gives satisfactory results, as will be shown later in Chapter 7, for few conditions, few services and two locations. However, when the control algorithm is extended to account for all services at all locations, the number of condition statements is increased dramatically to account for the many different possibilities. This produced a lengthy programme, which was less visible, difficult to modify, and too complicated to follow and check the logic of the algorithm. Therefore, this approach is not used in the development of control for the system of MSUs.

### 6.3.3 Conventional and Modern Controllers

Conventional control systems design relies on development of an explicit mathematical model of the controlled plant that adequately reproduces the characteristics of the plant with fidelity. The conventional three-term controllers or PID controllers (Proportional plus Integral plus Derivative controller) are the backbone of industrial control and well established in industry. In a PID controller (Figure 6.7), the proportional element has an input of the error \( e \) and output of \( K_{pe} \). The integral element has an input of \( e \) and an output which is proportional to the integral of the error with time, i.e. \( K_i \int e \, dt \). The derivative element has an
input of \((e)\) and an output which is proportional to the derivative of the error with time, i.e. \((K_d \frac{de}{dt})\). The output of the PID controller is the sum of these three elements and used to make correction to the process or the plant been controlled.

![Diagram of a PID controller](image)

**Figure 6.7: The basic form for a PID or three-term controller**

PID controllers are best used for controlling linear systems. Non-linear systems need to be controlled for short intervals where they can be linearized with some approximations. PID controllers are ubiquitous, simple and robust controllers. However, these controllers can only perform at their best at the nominal operating point of the plant about which the approximating holds. When the operating point moves away from the nominal point, their performance is invariably degraded due to the inherent non-linearity of the physical plant and a number of techniques have been proposed to anticipate this problem (King 1999).

Modern control is a rigorous methodology that has proved invaluable in finding solutions to well-structured control problems. With a few notable exceptions, however, its application to industry has been disappointing and few industrial controllers are designed with this methodology. The reason for this discrepancy are the complexity, uncertainty and vagueness with which industrial processes are characterized - conditions that do not allow for ready modelling of the controlled plant, essential to the applications of modern control methodologies (King 1999).

Some issues need to be mentioned regarding controlling the system of MSUs. The MSUs supply of services for the Hajj has multi-dimensional factors that incorporate human decisions, movements of visitors between different locations, shift in demands for services between these locations, variations in event programs and
variable traffic conditions. These factors make mathematical modelling for the services during the Hajj too complicated to model and will be based on many simplifications and assumptions, which makes such mathematical modelling far from reality. Moreover, in classical and modern control techniques, the response of the controller is usually gradual by continuous or with small discrete values such as changing voltage to control the speed of a motor or changing the amount of burnt fuel to control the temperature of a furnace. However, in the case of MSUs the response by sending or returning MSUs occurs with high discrete values relative to the change in demand. This creates sudden change in the service status that is considered as overshoot in classical and modern control techniques.

Therefore, the conventional and modern control methodologies are not used for controlling the system of MSUs for three reasons: firstly, the difficulty in developing a detailed accurate mathematical model for the Hajj. Secondly, the difficulty in interpreting the meanings of mathematical formulas used for controlling MSUs to ordinary service providers, which will limit their contribution in developing the control. Thirdly, the response of the control will be to release and send discrete numbers of MSUs of relatively high service capacity compared with the change in demand. This will result in a high value of overshoot that will usually cause instability in the system.

6.3.4 Intelligent Control

Intelligent controllers use a qualitative description of how a process operates instead of an explicit quantitative description of the physical principles that relates the causes to the effects on the process. An intelligent controller is therefore based on knowledge, stated linguistically in the form of production rules, which are elicited from human experts. Appropriate inference mechanisms must then be used to process this knowledge in order to arrive at suitable control decisions (King 1999) such as Expert systems, Artificial Neural Network, Fuzzy logic and Fuzzy-Neural networks.

Expert systems (Figure 6.8) permit a non-expert user to exploit the accumulated knowledge and experience of an expert in a specific field of expertise. Knowledge-
based expert systems use rules, data, events, simple logic and any other form of knowledge in conjunction with search techniques to arrive at decisions. However, where an element of knowledge is missing then the expert system cannot but return a "don't know" response, implying an inability to arrive at a decision. An expert system cannot extrapolate data and infer from similar or adjacent knowledge (King 1999). Therefore, an expert system is not suitable for use in controlling the system of MSUs for two reasons: firstly, since the system of MSUs is futuristic and not yet implemented, previous data that is needed to construct the Knowledge-base system is not yet available. Secondly, due to the possible failure of the expert system to arrive at control decisions about likely events relating to new situations during the Hajj that have not been experienced before.

![Figure 6.8: Basic elements of an Expert System](image)

Artificial Neural Networks (ANNs) are made up of dense parallel layers of simple non-linear neurons (or nodes), which are interconnected with varying weights (the synaptic weights) that completely specify the behaviour of the network once it has been trained (Figure 6.9). ANNs exhibit the properties of massive parallelism, robustness and are fault tolerant. They posses the ability to learn from experience instead of from models. The ability to generalize and relate similar inputs to similar outputs, the ability to generate any arbitrary non-linear functional relationship between their inputs and outputs, inherent stability, the ability to absorb new knowledge without destroying existing knowledge, and the ability to learn on-line, despite disturbances to the process (King 1991). Despite the many advantages of ANNs, they will not be used for developing the control of the system of MSUs in this research due to the need for previous data for training ANNs and the opaqueness of
the process when arriving at decisions. Once the system of MSUs has been
implemented and tested over many years, the ANNs can be trained from collected
data and used to confirm the decisions of the command centre.

![Feed-forward neural network](image)

*Figure 6.9: Feed-forward neural network*

Fuzzy controllers are increasingly used in modern control for consumer products,
industrial process control, medical instrumentation, manufacturing and decision-
The basic concept of Fuzzy logic uses linguistic words rather than numbers. In other
words, computing with words rather than numbers, which makes Fuzzy controllers
closer to human thinking with a high tolerance for imprecision. When one output is
directly related to one input by a giving formula, it is easy to write a program to
make the calculation. However, when more than one input is not directly related to
one or more outputs, programming becomes very complicated as many conditional
statements are needed to account for all possibilities and it is difficult to modify in
the future. The power of Fuzzy Logic is that it provides an efficient mapping
between multi inputs and outputs that are not necessarily directly related, is flexible
to modify in the future and is a very powerful tool for dealing quickly and efficiently
with imprecision and nonlinearity.

These characteristics make Fuzzy logic controllers very suitable for use when
controlling the system of MSUs for many reasons:

1) They require no explicit mathematical model for the Hajj,
2) the control will be based on linguistic rules that can be derived directly from the rules for providing services and logical reasoning,

3) the Fuzzy rules can be updated, discussed with officials and service providers and approved before the Hajj,

4) the ability of a Fuzzy controller to deal with the non-linearity and the multi-dimensional nature of the events of the Hajj,

5) the ability of Fuzzy controllers to arrive at a decisions for situations not experienced before.

6.3.5 Fuzzy logic controllers

The theories, sets, mathematics, methods, modelling and implementations of Fuzzy logic and Fuzzy controllers is well presented and explained in many texts such as King (1999), Cox (1999), Nguyen et.al (1999), Palm et al (1997) and Bandemer and Gottwald (1995). Therefore, it is not the aim of this section to give much detail about Fuzzy logic and Fuzzy controllers but to highlight some points that are of interest to this research.

Firstly, it is important to state the difference between “classical” sets and fuzzy sets to explain the work of Fuzzy logic controllers.

A classical set might be expressed as

\[ A = \{ x \mid x > 3 \} \]

A fuzzy set is an extension of a classical set. If \( X \) is the universe of discourse and its elements are denoted by \( x \), then a fuzzy set \( A \) in \( X \) is defined as a set of ordered pairs.

\[ A = \{ x, \mu A(x) \mid x \in X \} \]

\( \mu A(x) \) is called the membership function (or MF) of \( x \) in \( A \). The membership function maps each element of \( X \) to a membership value between 0 and 1. In other words, a membership function (MF) is a curve that defines how each point in the
input space is mapped to a membership value (or degree of membership) between 0 and 1.

To demonstrate the impact of using a classical or fuzzy sets when developing the logic for controlling the system of MSUs the following hypothetical example can be given. In service industry, it is common to ask customers to evaluate the level of service provided by giving a score within a range such as from 0 to 10 where 0 reflects the worst service and 10 the best.

The level of service can be described by a "classical" set by defining a score below which the service is 'Poor' such as 3 (Figure 6.10). If the score between 3 and 7 then the service described 'Acceptable'. If the score above 7 then service is 'Excellent'.

It can be seen that a "classical" set wholly includes or wholly excludes any given element, classical yes-no (Boolean) logic and truth value jumps discontinuously from 0 to 1. For instance, in the above example, if the average score for service level is 2.999 it is described 'Poor' whereas if it is 3.001 it is described as 'Acceptable'. This sudden change in evaluation, for a very small change in the input may be unfair if a penalty will be applied to 'Poor' service providers and a reward will be given to 'Acceptable' service providers. This disturbs the system if some control action needs to be taken for correction of a 'Poor' service.

The same example of the level of service can be described by Fuzzy sets as shown in Figure 6.11. It can be seen that the fuzzy membership function (or MF) 'Poor service' has intersection with MF 'Acceptable service' since a fuzzy set can contain elements with only a partial degree of membership. The same score of 2.999 mentioned above now has a membership value (or degree of membership) of 0.501 to MF 'Poor service' and a membership value of 0.499 to MF 'Acceptable service', therefore it is partially 'Poor' and partially 'Acceptable', so a service provider of this
score could have 0.501 of the penalty and 0.499 of the reward mentioned above. The same can be applied to any control action to be taken.

![Figure 6.11: Describing the level of service using Fuzzy sets](image)

The previous example demonstrates the benefits of fuzzy sets over classical sets in terms of allowing for smooth transition in applying rules applicable to one set or situation to rules applicable to another.

The fuzzy controllers to be used in this research are provided by the ‘Fuzzy Logic Toolbox’ of SIMULINK. A fuzzy logic controller is a convenient way to map an input space to an output space (Figure 6.12) using if-then rules. In other words, it is a method that interprets the values in the input vector and, based on some set of if-then rules, and assigns values to the output vector.

![Figure 6.12: Fuzzy logic controller maps inputs into outputs](image)

A simple fuzzy if-then rule can be of the form

\[
\text{if } x \text{ is } A \text{ and } y \text{ is } B \text{ then } z \text{ is } C
\]

Where \( A, B \) and \( C \) are linguistic values defined by fuzzy sets on the ranges (universes of discourse) \( X, Y \) and \( Z \), respectively. The if-part of the rule "\( x \) is \( A \)" and "\( y \) is \( B \)" are called the ‘antecedent’ or premise, while the then-part of the rule “\( z \) is \( C \)” is called the ‘consequent’ or conclusion.
To demonstrate the fuzzy interface process, Figure 6.13 represents a simple FLC that has 2 inputs and one output, each has 2 MFs and the process is shown in Figure 6.14. The rules for this controller are:

1. If (inputA is MFa2) and (inputB is MFb1) then (outputC is MFc2)
2. If (inputA is MFa2) and (inputB is MFb2) then (outputC is MFc1)
3. If (inputA is MFa1) and (inputB is MFb1) then (outputC is MFc1)
4. If (inputA is MFa1) and (inputB is MFb2) then (outputC is MFc3)

MathWorks (2000) mentioned that in the Fuzzy Logic Toolbox, there are five parts to the fuzzy inference process:

1) fuzzification of the input variables,
2) application of the fuzzy operator (AND or OR) in the antecedent,
3) implication from the antecedent to the consequent,
4) aggregation of the consequents across the rules, and
5) defuzzification.

Step 1. Fuzzify Inputs

The first step is to take the inputs and determine the degree to which they belong to each of the appropriate fuzzy sets via membership functions. In the Fuzzy Logic Toolbox, the input is always a crisp numerical value limited to the universe of discourse of the input variable (in this case the interval between 0 and 1) and the output is a fuzzy degree of membership in the qualifying linguistic set (always the...
interval between 0 and 1). Fuzzification of the input amounts to either a table lookup or a function evaluation. The implementations of this step to the simple FLC of Figure 6.13 is shown in Case-1, the upper part of Figure 6.14, where inputA = 0.352 and inputB = 0.436. The degree of membership of these two inputs to appropriate fuzzy sets can be seen in points-1, Figure 6.14.

Step 2. Apply Fuzzy Operator

Once the inputs have been fuzzified, the degree to which each part of the antecedent has been satisfied for each rule is known. If the antecedent of a given rule has more than one part, the fuzzy operator is applied to obtain one number that represents the result of the antecedent for that rule. This number will then be applied to the output function. The input to the fuzzy operator is two or more membership values from fuzzified input variables. The output is a single truth value. In the example, the results of applying an AND operator in this step, when takes the minimum values, appears in Figure 6.14, points-2.

Step 3. Apply Implication Method

Before applying the implication method, the rule's weight, if any, is applied to the number given by the antecedent. A consequent is a fuzzy set represented by a membership function, which weights appropriately the linguistic characteristics that are attributed to it. The consequent is reshaped using a function associated with the antecedent (a single number). The input to the implication process is a single number given by the antecedent, and the output is a fuzzy set. Implication is implemented for each rule. Points-3 in Figure 6.14 represents the output of this step by applying min (minimum) methods which truncates the output fuzzy set.

Step 4. Aggregate All Outputs

Since decisions are based on the testing of all of the rules in a FIS, the rules must be combined in some manner in order to make a decision. Aggregation is the process by which the fuzzy sets that represent the outputs of each rule are combined into a single fuzzy set. Aggregation only occurs once for each output variable, just prior to the fifth and final step, defuzzification. The input of the aggregation process is the
list of truncated output functions returned by the implication process for each rule. The output of the aggregation process is one fuzzy set for each output variable.

In Figure 6.14, all four rules have been placed together to show how the output of each rule is combined, or aggregated using max (maximum) methods, into a single fuzzy set (point-4) whose membership function assigns a weighting for every output value.

**Step 5. Defuzzify**

The input to the defuzzification process is a fuzzy set (the aggregate output fuzzy set) and the output is a single number. As much as fuzziness helps the rule evaluation during the intermediate steps, the final desired output for each variable is generally a single number. However, the aggregate of a fuzzy set encompasses a range of output values, and so must be defuzzified in order to resolve a single output value from the set. Point-5 on Figure 6.14 shows the result of applying the popular defuzzification method ‘centroid’, which returns the centre of area under the curve. Through this single value for output C, the process of arriving at an action or decision through FLC is completed.

Figure 6-14 represents two case studies. In Case-1, as described before, inputA=0.352 and inputB=0.436 while in Case-2 inputA=0.527 and inputB has the same value as in Case-1, therefore the difference between the two cases is only in the value of the first input.

In Case-1, the value of inputA intersects with MFa1 only and has no intersection with MFa2, therefore only Rules 3 and 4 will be fired as they consider the cases (inputA is MFa1) and the result from these two rules is outputC=0.319. In Case-2, the value of inputA=0.527 intersects with both MFa1 and MFa2, therefore, all of the four rules are fired and contributed to the final result of higher value of 0.464 for outputC.

This demonstrates that only rules with relevant values for the inputs are considered in decision making. Also, it is worth mentioning that in case-2, as the value of inputA has some degree of membership with both MFa1 and MFa2, it inherits both rules.
applicable to MFa1 and MFa2. This characteristic make Fuzzy Logic Controllers very powerful in arriving at decisions that consider many rules simultaneously, or in other words, takes all point of view into consideration.

![Diagram](image)

Figure 6.14: Demonstration of the evaluation process of a Fuzzy logic Controller

### 6.4 Developing Fuzzy logic controllers (FLC) for the system of MSUs

Different versions of Fuzzy logic controllers (FLC) are developed and tested in the search for controllers that issue the appropriate response for returning an existing MSU or sending additional ones in accordance with service status at each zone and other conditions on roads and support zones. Some of these versions are described below:
6.4.1 Version 1-1

In this version a FLC 'MSU_Request2' (Table 6.2) based inside each zone is used to issue requests for MSUs. It has three inputs, the first is 'Service-status' which reflects the service status inside the zone. Service status is the difference between the total capacity of service provided and the current population/demand at a zone. Service status of -4000 PU means that all pilgrims have already arrived at a zone but no service has been provided for them, zero means that the capacity of the service provided covers the current population exactly. A service status of 4000 means that the total capacity of MSUs provided covers the maximum population of a zone, but there is nobody, or there is an over-supply that exceeds the needs of current population by that amount. Three MFs 'Poor-supply', 'Good' and 'Over-supply' covering the range of [-4000 4000] PU, which represents absence of MSUs services, adequate supply and double the amount of services needed. MSUs will be needed to solve the problem of Poor-supply status, while over-supply status allows for returning unneeded MSUs.

The second input 'Population-change' represents the rate of change of population at a zone. It is given the range [-1.2 1.2] with two MFs 'Decreasing' and 'Increasing'. If the rate of change is negative, it indicates that population is decreasing and the need for service will be less than for a positive rate of change which means the population is increasing.

The third input is 'Service-capacity-change'. It represents the change of service capacity provided within the range [-1.2 1.2] for two MFs 'Decreasing' and 'Increasing'. If it is decreasing, MSUs are leaving the zone. If it is increasing, then MSUs are coming into the zone and soon service status will be better.

The result for evaluation of the three inputs mentioned above is the output 'MSU-request' and is in the range [0 10] for three MFs; 'not-used', 'Normal' and 'Urgent' to indicate whether an MSUs is not used. Therefore, it can be sent to another zone, the situation is normal so no action is needed, or there is a shortage and an MSU is needed.
Twelve rules are used to define the control and presented in tabular form in Table 6.2. Some of these rules are as following:

Rule 1: IF 'Service-status' is 'Poor-supply' and 'Population-change' is 'Increasing' and 'Service-capacity-change' is 'Decreasing' THEN 'MSU-request' is 'Urgent'

Rule 6: IF 'Service-status' is 'Good' and 'Population-change' is 'Increasing' and 'Service-capacity-change' is 'Increasing' THEN 'MSU-request' is 'Normal'

Rule 12: IF 'Service-status' is 'Over-supply' and 'Population-change' is 'Decreasing' and 'Service-capacity-change' is 'Increasing' THEN 'MSU-request' is 'not-used'

<table>
<thead>
<tr>
<th>Service-status</th>
<th>Population-change</th>
<th>Service-capacity-change</th>
<th>'Decreasing'</th>
<th>'Increasing'</th>
</tr>
</thead>
<tbody>
<tr>
<td>'Poor-supply'</td>
<td>'decreasing'</td>
<td>'Normal'</td>
<td>'Normal'</td>
<td></td>
</tr>
<tr>
<td>'Increasing'</td>
<td></td>
<td>'Urgent' (R1)</td>
<td>'Normal'</td>
<td></td>
</tr>
<tr>
<td>'Good'</td>
<td>'decreasing'</td>
<td>'Normal'</td>
<td>'not-used'</td>
<td></td>
</tr>
<tr>
<td>'Increasing'</td>
<td></td>
<td>'Urgent' (R6)</td>
<td>'Normal'</td>
<td></td>
</tr>
<tr>
<td>'Over-supply'</td>
<td>'decreasing'</td>
<td>'not-used'</td>
<td>'not-used' (R12)</td>
<td></td>
</tr>
<tr>
<td>'Increasing'</td>
<td></td>
<td>'not-used'</td>
<td>'Normal'</td>
<td></td>
</tr>
</tbody>
</table>

6.4.2 The FLC 'Approval'

The requests from zones are evaluated in the command centre using the fuzzy controller 'Approval' that takes into consideration availability of MSUs and traffic conditions. The controller has three inputs and one output. The first input is 'MSU-request' that is already sent from zones as described in the previous subsection. Three MFs for 'not-used', 'normal' and 'Urgent' MSU-requests. The second input is 'MSU-availability' in the range of [0 1] where 0 indicates that there are no MSUs
available at the support zone and 1 shows that all MSUs are available, with three MFs for 'Low', 'Medium' and 'High' availability of MSUs. The third input is 'Traffic-Volume-to-zones' which has the range [0 75] where 0 indicates that no vehicles are moving on the road while 75 shows that the road is full and traffic volume has reached its maximum of 75 LV/hr, therefore no MSUs should be allowed to move. Three MFs describe traffic volume conditions with 'Low', 'Medium' and 'High' traffic volumes. The output of the controller is 'MSU-approval' that represent the approval or disapproval when sending an MSU to a zone. Five MFs represent the degree of approval in the range [0 1] where 0 is for complete disapproval and 1 is for complete approval. These MFs are 'Not-approved', 'Stand-by', 'Normal', 'Approved' and 'Highly-Approved'. Table 6.3 shows the rules for Fuzzy controller 'Approval'.

<table>
<thead>
<tr>
<th>'MSU-request'</th>
<th>'Normal'</th>
<th>'urgent'</th>
<th>'Unused'</th>
</tr>
</thead>
<tbody>
<tr>
<td>'Low'</td>
<td>'Low'</td>
<td>'Low'</td>
<td>'Low'</td>
</tr>
<tr>
<td>'High'</td>
<td>'Approved'</td>
<td>'Approved'</td>
<td>'Approved'</td>
</tr>
<tr>
<td>'Medium'</td>
<td>'Normal'</td>
<td>'Not-approved'</td>
<td>'Not-approved'</td>
</tr>
<tr>
<td>'Low'</td>
<td>'Approved'</td>
<td>'Not-approved'</td>
<td>'Stand-by'</td>
</tr>
<tr>
<td>'High'</td>
<td>'Highly-Approved'</td>
<td>'Approved'</td>
<td>'Highly-Approved'</td>
</tr>
<tr>
<td>'Medium'</td>
<td>'Highly-Approved'</td>
<td>'Approved'</td>
<td>'Highly-Approved'</td>
</tr>
<tr>
<td>'Low'</td>
<td>'Not-approved'</td>
<td>'Not-approved'</td>
<td>'Not-approved'</td>
</tr>
<tr>
<td>'High'</td>
<td>'Stand-by'</td>
<td>'Not-approved'</td>
<td>'Not-approved'</td>
</tr>
<tr>
<td>'Medium'</td>
<td>'Not-approved'</td>
<td>'Not-approved'</td>
<td>'Not-approved'</td>
</tr>
</tbody>
</table>

6.4.3 Simulation results for Version 1-1 of the General Model

Different control settings are trailed for different simulation runs for this version. Some results for these simulations are shown in Figure 6.15. It can be seen that the control response for demand is acceptable for some parts but in general the response is not acceptable at all due to defects such as: unjustified over supply (1), severe under-supply (2), unstable orders to send and return MSUs (3), late response to demand (4), late release of unneeded MSUs (5) and unjustified sending of MSUs (6).
Figure 6.15: Some simulation results for Version 1-1 of the Model showing main unacceptable control response.

(1) Unjustified over supply, (2) severe under-supply, (3) unstable orders to send and return MSUs, (4) late response to demand, (5) late release of unneeded MSUs and (6) unjustified sending of MSUs.

6.4.4 Versions 2 to 5 of the General Model

In version 2, two inputs for FLC 'Request2' are attempted to solve some problems with version 1-1, mainly the over supply of service even though it is not needed and making requests even when there is no population. The first is 'Total population' to account for the actual population at the zone. The second is 'Ratio of Service status to MSU service capacity' to account both for MSU service capacity and service status. These two inputs replaced the rate of change of population and rate of change of service capacity.

In version 4, Fuzzy inputs and outputs for MSU Request are extended and refined. To account for future need for an MSU, a variable 'Next-Peak' is introduced to account for the need for the 'currently Not-needed' or 'low needed MSUs' before releasing it. It has three MFs 'Close', 'Far', and 'Never'. If it is 'Close' the same MSU will remain until the next peak. If it 'Far', it may be released if another MSU is
scheduled to arrive. If it is ‘Never’, it should be released, as there will be no need for it at all. Graphs for the relationships between demand, supply, service status, next peak and MSU capacity are used to derive the appropriate output of the fuzzy block. Fuzzy inputs and outputs for MSU Orders at the Control in the Support zone are also extended and modified. A specially written MATLAB function (MsuOrders) is introduced to issue orders to return MSUs, make them available to other zones, and to send MSUs to zones that need them. The algorithm takes into consideration the importance of modified MSU requests from the output of the fuzzy block. Also it returns the unneeded MSUs according to their value and the need for them in other zones (see the comments about the algorithm). This function replaces the logical blocks that automatically return MSUs below certain values as used in previous versions of the model. Also two factors are added to ensure instant return of unused MSUs below certain level, and instant acceptance of highly needed MSU above a certain level. Approval of sending and retuning MSUs is in accordance with their importance.

In version 5, the fuzzy input ‘next peak’ for fuzzy controller MSU-Request is replaced by ‘Future Status’ to solve the problem in Muzdalifah where the next peak has a small value which results in not ordering MSUs. Current Relative Service Status has 7 MFs; ‘Negative-Very-High’, ‘Negative-High’, ‘Negative-Low’, ‘Okay’, ‘Positive-Low’, ‘Positive-High’ and ‘Positive-Very-High’. The ‘Future Relative Service Status’ also has 7 MFs taking the same names. The output of the FLC ‘Request’ is given 8 MFs ‘Top-Priority’, ‘Urgent’, ‘High’, ‘Low’, ‘No-Request’, ‘Need-Low’, ‘Need-Very-Low’ and ‘Not-Needed’.

In version 6-1, Fuzzy roles for MSU Requests in Version 6 are modified by changing to Gaussian instead of triangular, and a modification is made so extra MSUs could be fixed or variable. In version 6-2 the location of curves for some MF inputs are shifted to allow for unequal conditions for returning and requesting MSUs in an attempt to prevent the instability of the system observed from the results of version 6-1.

In version 6-3, the input ‘Relative Accumulated Future demand’ that represents the integration of demand relative to service capacity of an MSU over a period of time,
is replaced by the ‘*Future Relative Status*’ that compares the expected service status after a specified period of time relative to MSU service capacity. The membership functions for MSU-Request are modified by reducing the MFs with current service status from 7 to 3 and modifying the shapes of fuzzy sets.

In version 6.5, a fixed transportation delay of 14 simulation steps (21 minutes) is applied to signals of MSUs sent to zones to account for transportation time from one zone to another. This time may not always be sufficient for transportation, but is used to account for the sent MSUs in the next evaluation cycle. Version 6.5 is later modified to provide enough transportation time and modification is made to account for MSUs on the road when making requests for services, by considering them within the calculation but not within actual supply curves.

In version 7, expected bus traffic volumes are considered when making decisions as to whether MSUs can be sent later when needed or if they should be sent now if roads are predicted to be crowded at that time. For instance, in the case of Muzdalifah, it will be too crowded to send MSUs after the sunset of day 9. Therefore, MSUs should be sent before with sufficient time. The function ‘*MsuFuzOrders*’ is modified to ‘*MsuFuzOrdersTrfc*’ to account for future bus traffic volume through an additional input. Although one input is added, the total number of rules is reduced due to reduction of MFs for fuzzy inputs and combination of some rules using OR and Non.
6.5 The developed control for the system of MSUs

The different versions of the general model, mentioned beforehand, helped better understand the interaction between the different components and gradually develop controllers. The final developed control of MSUs (Othman and Parkin, 2003/2) is based on three stages as shown in Figure 6.16, and derived from the general model of the system (Figure 5.6 of Chapter 5).

During the first stage, each zone evaluates its need for MSUs based on the situations inside that zone then issues an MSU-request to the control centre stating the degree of need to keep an existing MSU within the range of [-10 0] or the degree of need for an additional one within the range of [0 10]. These requests represent the microscopic point of view of each zone after evaluating the situations inside. The Fuzzy logic controller 'Request33' is used for evaluation and issuing MSU-requests.

Figure 6.16: The three stages for controlling the system of MSUs.
Stage 1: zones issues MSU-requests,
Stage 2: control re-evaluate all MSU-requests on a macroscopic scale and
Stage 3: control issues orders to MSUs.
will be described in the next section. This configuration distributes the computing load to zones according to the need of MSUs, instead of the control centre and makes the model more visible and easier to develop.

During the second stage, all MSU-requests from all zones are re-evaluated simultaneously by the control centre. A fuzzy logic controller ‘MsuFuzOrdersTraffic’ is assigned to each zone and is used to re-evaluate the MSUs-requests based on current situations at the support zone. This will be discussed in detail in the proceeding sections. The outputs are the modified values for MSU-Requests that take into considerations the situations in the system as a whole. In other words, the outputs represent the macroscopic point of view of the control centre for the service situations at all zones taking into consideration other situations within the system as a whole.

During the third stage, a specifically written MATLAB function based at the control centre sorts the modified MSU-Requests according to their relative importance then executes the appropriate control actions for releasing MSUs from zones that have no need for them, it then sends MSUs to zones that are desperately in need of them or takes no action. This will be discussed later. Through the response from the control centre, closed control loop is complete.

6.5.1 MSU Request subsystem and FLC ‘Request33’

The sub-system MSU-Requests (Figure 6.17) is located inside each zone. It contains the fuzzy logic controller ‘Request33’, which issues a score for returning an existing MSU [-10 to 0] or a score for requesting an additional one [0 to 10] based on service conditions inside that zone fed as inputs to the controller. The first input is the ‘Relative services status’ (the ratio of current service status to MSU service capacity) calculated from the outputs of two direct look-up tables that extract the value of current ‘service status’ and the value of ‘MSU-capacity’ for the MSUs-group under investigation. The second input to the controller is the rate of change of population calculated by a derivative block. The third input is the value of ‘Expected relative service status’. After a specified period of time ‘FutureTimeSpan’ is evaluated by a specifically written MATLAB function ‘RltveFutServStat’. Three saturation blocks
limit the minimum and maximum values of the three inputs. The settings of the first and the third inputs are set to [-2 2] in order to reflect up to double the service capacity of MSUs under investigation, i.e. the value of -2 represents a shortage of services by two MSUs. The second input is limited to the range of [-10 10] based on the values of rate of change of population in the four cities (Figure 6.18). Although the rate of change reaches up to 17.7 and down to -14 in some cases, the range is limited to [-10 10] to prevent neglecting small variations.

MSU Requests

![Diagram](image)

**Figure 6.17: The subsystem MSU-Request**

![Graphs](image)

**Figure 6.18: The rate of change of population at the four cities
a) Makkah, b) Mina, c) Arafat and d) Muzdalifah**

A transport delay block is used to keep record of the output of the FLC during the last evaluation cycle by applying a delay of 16 simulation steps to the signal. The output of the delay block is added to the output of the FLC and multiplied by 0.5 to
obtain the average. This average of the outputs of the FLC is used instead of the current output to ensure system stability as will be discussed later. A switch block is used to prevent passing the average output signal of the FLC in the case where no pilgrims and no MSUs are in the zone. This condition is achieved by comparing the sum of population and absolute value of service status with a threshold of zero. If pilgrims or MSUs exist in the zone, their sum will be above zero and the signal will be allowed to pass. This condition is used to prevent issuing requests for MSUs from zones that have no pilgrims to serve or MSUs to return.

The Fuzzy variables (the three inputs described above), their Fuzzy Membership Functions (MFs) and the output of the FLC 'Request 33' are represented in tabulated form in Table 6.4. The first Fuzzy variable 'ServiceToCapacity' is given three MFs: 'NegVeryHi', 'Ok' and 'PosVeryHi' for describing service situations of under supply, acceptable and over supply, respectively. The second variable 'PopulationChange' is given three MFs: 'Falling' to describe the situation of decreasing population when pilgrims are leaving the zone, 'NoChange' when not many pilgrims come to a zone or leave it and 'Rising' when pilgrims are arriving. The third variable 'FutureNeed' is also used to describe the service situation as the first variable but for the near future after a defined period of time. The output of the FLC 'MSU-request' is the result of evaluation of service situations presented in 9 MFs, four of them to describe the degree of need for an existing MSU using MFs 'NotNeededAtAll', 'NotNeeded', 'NeedVeryLo' and 'NeedLo'. One MF 'NoReq' represents that situation is acceptable and there is no need to return or to send an MSU. The remaining four MFs describe the degree of need for an additional MSU namely, 'Low', 'High', 'Urgent' and 'TopPriority'. The total number of roles due to these three inputs and their MFs is 27 as presented in Table 6.4.
Figure 6.19 represents the three inputs, the shape of their MFs, their rules in indexed form and the output with its 8 MFs. The Gaussian shapes for the MFs are used to give a smoother control surface and to give proximate values for inputs near their extreme ends. The MFs are made to overlap and to inherit some characteristics from rules applicable to nearby values. This is useful to avoid discontinuities in decision-making, and to avoid regions of inputs that fire no rules or make sudden requests for MSUs.
Figure 6.19: Fuzzy inputs, rules and output for the final model of the Fuzzy logic controller 'Request33'

Figure 6.20 represents the 27 roles for the situations defined by the three inputs, the implication of rules and the evaluation result of the FLC 'Request33'. The figure represents the evaluation of one case study given as a demonstration. The first input 'ServiceToCapacity' has a value of -0.5 which indicates that there is a relatively high shortage of service equal to half the capacity of an MSU. This value falls only in the region of 'NegVeryHi' therefore it fires the first 9 rules only. The second input 'PopulationChange' reports that pilgrims are leaving the zone at a relatively slow rate of -0.6 which has intersections with the three MFs for this input. Therefore, some decisions will be inherited from nearby rules. The third input 'FutureNeed' has a value of -0.3 which indicates that after a certain time defined by 'FutureTimeSpan', it is expected that there will be some shortage of service but less than the current situation. The 9 rules contribute in some degree to decision making. Currently there is shortage of service provided but pilgrims are leaving the zone and the shortage of service is expected to be less in the near future, therefore, the evaluation is: there is no severe need for an additional MSU now, but if it is provided that would be nice as it will serve for some time. This evaluation gives a score of 2.76 for 'MSU-request' and will be reported to the control centre.
6.5.2 The Control Centre at the Support Zone

The control centre at the support area has six main subsystems (Figure 6.21). The 'Event Programs' subsystem represents the events of the Hajj and produces the variation of population at the different cities with time as described previously in Chapter 5. These outputs are feed to subsystems 'Buses to zones' and 'Buses out from zones' to generate orders to buses to transport pilgrims to and out from zones according to the previous description. The fourth subsystem 'Traffic volumes' calculates the traffic volume due to the movements of buses and MSUs at every simulation step as described before in Chapter 5. This will be considered in decisions for releasing or sending MSUs to zones. The fifth subsystem 'MSUs Movements' responds to the requests for services from all zones within the loop by making decisions and issues orders to return unneeded MSUs from zones and sends MSUs to needy zones. This will be described in detail in the following sections. The last subsystem 'MSUs Availability' calculates the remaining MSUs available at the support zone which are ready to be sent to serve at any zone within the same loop.
6.5.3 Evaluation of MSU availability

This subsystem ‘MSU-availability’ (Figure 6.22) calculates MSU availability defined by the ratio of available MSUs at support zone to the total MSUs in the system. The total number of MSUs available in the system for the service under investigation is extracted from the data base by MSU-Total-Batches subsystem. The total number of MSUs sent to zones up-to the last simulation step is calculated by integrating MSUs sent to zones (MSUs are in Makkah zones at the beginning of simulation). The Matlab function (Sum-16) sums the total number of MSUs under investigation at all zones. The number of MSUs released from zones is integrated to include MSUs released at the current simulation step.

The MSU-total-batches sub-system (Figure 6.23) extracts the total number of MSUs for one zone from the database, multiplies it by 4 to account for the number of MSUs needed for the four zones. This is then multiplied by a predefined value for the extra MSUs. The ‘Extra-MSUs’ variable is used in the simulation to calculate the additional percentage of MSUs needed for acceptable service level at all zones, taking into consideration that some MSUs will be still needed at some zones while visitors are moving to another.
6.5.4 The subsystem ‘MSUs Movements’

This subsystem represents the core for modelling and decision making for the movements of MSUs (Figure 6.24). MSU-Request signals from all zones are issued according to the procedure described previously and are separated using a ‘Demux’ block and fed with other inputs of ‘MSU-Availability’, ‘Traffic-Volume’, and ‘Future-Buses-Traffic-Volume’ to 16 subsystems ‘MSUs-to-zone-no.’ representing the 16 zones of the loop. Each subsystem contains the FLC ‘MsuFuzOrdersTrfic’ (Figure 6.25) as will be discussed in the next section. The outputs of these 16 subsystems are the re-evaluated scores for MSUs requests, which are combined together using a Matrix Concatenation block. This output is fed to a specially written MATLAB function ‘MsuOrders2’ which sorts the re-evaluated MSUs-requests and then issues orders for returning and sending MSUs according to some considerations.
that will be described later. The output of the function is a [16, 2] matrix which assign a value of 1 for sending an MSU, 0 for no action and -1 for returning or releasing an MSU. Orders for returning MSUs are checked with the actual MSUs available at zones. A simple specially written MATLAB function is used to convert the [16,1] signal of returning MSUs to a [16,16] signal were zones are in rows and service groups are in columns. An Initial Condition block is used to confirm that no MSUs will be returned at the beginning of simulation on the first simulation step. The signal for returning MSUs is multiplied by the capacity of MSUs and sent as the first output of the subsystem ‘MSUs Movements’. This is sent directly as the second output of the subsystem. Orders to send MSUs are treated the same way to form the third and the fourth outputs of the subsystem.

**MSUs Movements**

![Diagram of MSUs Movements subsystem](image)

*Figure 6.24: The subsystem ‘MSUs Movements’*
6.5.5 The Fuzzy Logic Controller 'MsuFuzOrdersTrfic'

As mentioned in the previous section, requests from all zones are re-evaluated at the control centre using the FLC 'MsuFuzOrdersTrfic' (Figure 6.26) in order to consider other factors affecting the whole system. This controller has four inputs. The first is the 'MSU-request' sent from the zone. This controller re-evaluates and limits to the range [-10 10] using a saturation block. The second input is 'MSU-Availability' that was already calculated before by the subsystem 'MSUs Availability' and is limited to the range [0 1] to indicate if no MSUs are available at the support zone or if all of them are available. The third input is the traffic volume calculated by the subsystem 'Traffic volumes' limited to the range [0 75]; 0 indicates that no vehicles are on the road whereas 75 indicates that the road is completely full and no more vehicles should be allowed in. The fourth input is the 'Future-Buses-Traffic-Volume' that reflects the expected number of buses in the near future after a period of time specified by 'FutureTimeSpan' and limited by a saturation block to the range [0 65] to allow some room for top-priority MSUs to move.

The inputs, their MFs and rules for this controller are presented in Table 6.5. To keep the number of rules within an acceptable range, the number of MFs for these inputs is reduced. The 'MsuRequest' input is given five MFs (instead of 9) describing the status of unneeded MSUs as 'NeedLow' and 'NotNeeded', the status of good conditions with no need to return or to send MSUs 'NoReq' and the status that needs additional MSU 'HiReq' and 'Urgent'. The 'MsuAvailability' input is given two MFs; 'Available' and 'Rare' to indicate whether too many MSUs are available at the
support zones; so most request can be answered, or very few so that only very important request can be answered. The third input ‘CurrentTrafficVolume’ reflects the current traffic volume in the loop and is given two MFs ‘TrficLow’ to indicate that traffic volume is low so that many MSUs can be moved and ‘TrficHigh’ to indicate that not much space is left for moving MSUs. The fourth input is FutureBusTraffic and is given two MFs to describe the expected traffic volume due to the movement of pilgrims buses. ‘FewBuses’ indicates that in the near future there will be few buses on the road so many MSUs can be moved at that time and ‘ManyBuses’ indicates that not many MSUs will be allowed to move after a certain time to give priority to the mass transportation of pilgrims from one zone to another, requiring a huge number of bus trips. The shape of MFs for inputs, rules in indexed form and shape of MFs for the output are presented in Figure 6.26.

Tabel 6.5: Fuzzy inputs and output for the Fuzzy Logic Controller
‘MsuFuzOrdersTrfic’

<table>
<thead>
<tr>
<th>CurrentTrafficVolume</th>
<th>'TrficLow'</th>
<th>'TrficHigh'</th>
</tr>
</thead>
<tbody>
<tr>
<td>FutureBusTraffic</td>
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<td></td>
</tr>
<tr>
<td>'FewBuses'</td>
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</tr>
<tr>
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<td>'ReturnMSU'</td>
<td>'NoAction'</td>
</tr>
<tr>
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<td>'NoAction'</td>
<td>'NoAction'</td>
</tr>
<tr>
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<td>'NoAction'</td>
<td>'NoAction'</td>
</tr>
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<td>'SendUrgent'</td>
<td>'SendNormal'</td>
</tr>
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<td>'SendUrgent'</td>
<td>'SendNormal'</td>
</tr>
<tr>
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</tr>
<tr>
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</tr>
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</tr>
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<tr>
<td>'ManyBuses'</td>
<td>'NoAction'</td>
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<td>'SendNormal'</td>
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</table>

<table>
<thead>
<tr>
<th>MsuRequest</th>
<th>'NoNeed'</th>
<th>'NoReq'</th>
<th>'Urgent'</th>
<th>'NeedLow'</th>
<th>'HiReq'</th>
</tr>
</thead>
<tbody>
<tr>
<td>'Rare'</td>
<td>'ReturnMSU'</td>
<td>'ReturnMSU'</td>
<td>'NoAction'</td>
<td>'MayReturned'</td>
<td></td>
</tr>
<tr>
<td>'Available'</td>
<td>'NoAction'</td>
<td>'NoAction'</td>
<td>'NoAction'</td>
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<tr>
<td>'Rare'</td>
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<tr>
<td>'Rare'</td>
<td>'SendUrgent'</td>
<td>'SendUrgent'</td>
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<tr>
<td>'Rare'</td>
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<td>'SendNormal'</td>
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<td>'NoAction'</td>
<td>'SendNormal'</td>
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</table>
In order to demonstrate the re-evaluation process for the controller, Figure 6.27 shows the implementation of the rules of Table 6.5 for one case study. An 'MSU-request' of score 4.9 (out of 10) is issued from the relevant zone indicating a relatively high need for an additional MSU. This fires the rules that have MFs containing this score. The second input 'MsuAvailability' has a value of 0.3 (out of 1) which indicates that not many MSUs are currently available at the support zone. The third input 'CurrentTrafficVolume' with its value of 50 (out of 75) reports that roads are currently crowded while the fourth input 'FutureBusTraffic' with its value of 22 (out of 65) expects that in the coming future, not many buses will be on the road.
The situation can be described as follows: A particular zone has a relatively high need for an additional MSU, but there are few available in the support zone and roads are too busy now but are expected to be better after some time. Therefore, the decision is to wait some time for better conditions, which is translated by reducing the score of 4.9 to 1.34 for 'MsuOrders'. Reducing the scores for relatively high MSU-requests under situations of limited resources and busy roads gives priority for very important MSU-request to be answered.

Figure 6.27: The implementation of rules for the Fuzzy logic controller MsuFuzOrdersTraffic for one case study
6.5.6 The specially written MATLAB function 'MsuOrders2'

The tasks of this function are to issue orders to return unneeded or slightly needed MSUs and sends MSUs to zones according to their relative importance. It receives the matrix containing 'MsuOrders' for the re-evaluated MSUs-request from all zones as described in the previous section. The other inputs to this function are: The number of MSUs available at the support zone, the 'Instant Acceptant Score', the 'Min Acceptance Score', the 'Max Return Score', the 'Instant Return Score', traffic volume to zones, the batch size of the MSU and the number of the service-group under investigation.

The algorithm for this function can be summarized as follows in conjunction with Figure 6.28:

1. **Return** MSUs from zones of scores below the 'Instant Return Score' as they are not in need any more. Stop returning them if 'traffic volume' approach maximum limit, but still make them available for urgent needs.

2. **Send** MSUs urgently to all zones scoring above the 'Instant Acceptant Score' since they are badly in need of them, returning MSUs from less needy zones if no MSU is available at the support zone. Stop sending them if the total traffic volume for buses on the road and MSUs to be sent exceeds 75 (Large vehicles/simulation step).

3. **Send** MSUs to the highest need zones that scored above 'Min Acceptance Score' and return MSUs from the least needy zones scored below 'Max Return Score', if necessary, provided that it dose not contradict the previous 10 orders. Stop if traffic volume will exceed 75 LV/Simulation step.

4. **Do no actions** for zones scoring above 'Max Return Score' up to below 'Min Acceptance Score' as these zones are in balance between demand and supply of service and sending or releasing MSUs from them will disturb this balance.
6.5.7 The Stability of the control of the system of MSUs

Unstable orders occur when an MSU is returned from a zone where it was just sent during previous orders and vice versa. Such unstable or inconsistent orders cause confusion to MSU operators and increases the traffic volume.

The control of the system is improved gradually through the different versions of the model. It is noticed that some unstable orders to MSUs occur frequently, mainly due to the high discrete value for MSU service capacity (relative to service capacity provided) that when removed or added to the system creates overshoot that disturbs the system. Therefore, different techniques were tested before achieving system stability.

In the final general model, the technique used to achieve stability for MSU-requests is as follows:

1) Take the average of current MSU-request and the previous one instead of using the current request alone. Therefore, if one request is positive and the
other is negative, then the average will compensate these contradicting requests and the result will be closer to zero with no request or a very low priority request. If both requests are positive or negative and both have high values, the average confirms consistency of MSU-requests and will be of high value to reflect high priority. If the previous order is zero or very low then the average will reduce the value of the current order, hence reducing the priority of sudden orders.

2) Stabilizing or damping the orders to send or to return MSUs, by adding conditions to 'MSU-order2' algorithm such that if the new order contradicts any previous 10 orders, such as returning an MSU that was just sent in any of the previous 10 orders, or vice versa, then no order is issued. This restriction is logical since the algorithm 'MsuOrders' described before ensures that no order to send or to return an MSU will be made unless it is fully justified, hence there is no point in changing it very soon. The 10 orders take 10 evaluation cycles to be issued, which is equivalent to 4 hr. This means that any MSU will spend at least 4 hr in any location before being assigned a new job. This gives MSUs operators enough time to earn money and reduces the number of trips.

6.6 The validity of the model for the system of MSUs

Modelling and simulation is found to be a valuable and essential tool for investigating the system of MSUs. This is due to the criticality of testing such a new concept or conducting a wide scale experiment on the mega event of the Hajj. Such experiments could be risky, expensive, and impractical to conduct. On the other hand, modelling the system gave deep insight of the different components of the system and the interactions taking place between them. More importantly, it allowed a large number of simulation experiments to be conducted while developing the general model and the control for the system, with no cost or real risk.

The validation of the general model for the system was confirmed gradually throughout the different stages of the developed model:
1- Starting by developing a very simple model of the system, as described before in chapter 5, the suitability and the capabilities of the modelling and simulation software (Simulink and MATLAB) to model the system were tested.

2- The simple model is extended to a Preliminary Model, which confirmed the suitability of the software and achieved a wider perspective of the model with more variables added. The Preliminary Model was tested through simulation and the results were published (Othman and Parkin, 2002).

3- Based on the findings of the Preliminary Model, the General Model was developed gradually through different versions. At each stage of the development, a small incremental improvement was introduced and tested by running the simulation to confirm its functionality and the consistency of its outputs, before introducing further developments.

4- Finally extensive simulation runs were used to confirm the validity of the General Model and the changes to the variables at the different parts of the model were presented in graphs. Any malfunctions, un-preferred responses or unexpected behaviour could be detected and modifications or corrections were made accordingly.

5- The validity of the General Model was confirmed by publications (Othman and Parkin, 2003/1 and 2003/2).

It can be concluded that the general model is a good representation of the major components of the system and can be considered a valid tool for testing the proposed system of MSUs through simulation.

6.7 The validity of the proposed designs for the system of MSUs

The methodology used for investigating the proposed system of MSUs from the design point of view, as described before in Chapter 3, is based on an intensive web search for the available mobile services offered on the international market, frequent field visits to the cities of the Hajj during the Hajj and Ramadan season, and
discussion of design issues with experts in the Hajj and the architect of the master plan.

The validity of the web sources is assured from visits to the web sites of the manufactures and suppliers of mobile services, where real products are well developed, tested and offered to the international market. Some ready-made units may require custom modifications for better matching the Hajj environment. The wide spectrum of available mobile units designs suggests that almost any service can be specially designed to be mobile and can be specially made by the existing manufactures using the existing technology.

The validity of the general design of the system is confirmed through frequent field visits during the Hajj 2001, the Hajj 2002 and Ramadan 2001, which can be summarized as follows:

1- The field visits allowed the researcher to examine different proposals and designs on site, as if they were implemented in the real environment. This allowed him to question and challenge these proposals in the light of field conditions and modifying them accordingly.

2- A large number of photos and video recordings was taken during field visits and used intensively for further visualization of the environment of the Hajj and better understanding of the interaction of pilgrims with services.

3- Students from the CTHM Institute for Hajj Research were assigned to observe and to collect data for different types of services, as described before in Chapter 4. This allowed for deeper understanding of the process of providing services for pilgrims.

4- A series of meetings and presentations were conducted, in Makkah and Riyadh, with highly qualified personnel in different fields. They were informed of the proposed system and their valued feedback confirmed the validity of the concept and helped to develop the system further. Of particular value was the meeting with the Architect of the master plan where the system of MSU and the proposed modifications to the master plan to
account for MSUs parking were discussed in details. This confirmed the validity and practicality of these modifications.

5- The availability of local resources for making MSUs was confirmed during field visits and through meeting some managers of bus companies.

It can be concluded that the design of the proposed system of MSUs is developed in the light of field conditions, experts’ vision, international products and personal experience. This was validated through deep discussion and positive feedback with highly qualified personnel. The success of the operation of these MSUs once implemented can be extrapolated from the current success of the existing mobile services available on the international market.

6.8 The validity of the survey conducted to investigate the opinions of service providers regarding the proposed system of MSUs

The opinions and suggestions of the service providers working during the Hajj about the proposed system of MSUs is considered important for the research since they are the main stakeholders once the system is implemented. Therefore, their experience in providing services for the Hajj is valuable for developing the system further. Since this information is stored in their memory, and when it comes to know what people believe or think it is better to ask them, therefore, a survey was conducted amongst the service providers using the questionnaire developed and tested previously in Chapter 3.

The validity and quality of the data collected by the questionnaire were assured throughout the various stages of designing the questionnaire, distribution process, collection procedure, data entry and data analysis.

The validity of the design of the questionnaire was assured by pilot testing and modifying the final questionnaire accordingly, as described before in Chapter 3. This ensures that the questionnaire is self-explanatory and can be understood and answered easily by the respondents themselves without any assistance.
The validity of the distribution and collection procedure of the questionnaire was assured through the following:

1- Using the questionnaire distribution facilities at the CTHMIHR, Umm Al-Qura university, Makkah. The procedure benefite from the good reputation of the institute, its strong connection with all governmental bodies and private sector working on the Hajj. The Institute has well developed facilities and procedures, and its location is in the main city of the Hajj, Makkah, where data were collected.

2- Assigning experienced senior undergraduate students the task of distributing and collecting the questionnaire. They were selected to be of Saudi nationality for better communication with Saudi managers and supervisors, and to be residents of the city of Makkah so that they know where to distribute the questionnaire.

3- Using a follow up procedure employing official letters to encourage the respondents to answer and to return questionnaires.

The validity and the quality of the answers to the questionnaire was assured by the following:

1- Questionnaires were left with the respondents and collected a few days later to give them the privacy they need to answer critical questions honestly, without biased answers, and to give them enough time to answer the questionnaire at their most convenient time.

2- The questionnaire was written in the native language of the respondents (Arabic), to ensure that they understood the questions and the possible answers properly and to make it easier for them to answer open ended questions and to write their comments.

3- The tabular format for the possible answers to the questions and the ticking process used helps to make the questions easier to answer and gives a meaningful visual indication of the rating values. (See for example question 9, Appendix A).

4- The type of questions used in the questionnaire are mainly closed-ended questions that usually include one open ended answer (Other:...........).
This allows the respondent to give another answer that was not included in the options. This proved to be very helpful when checking the returned questionnaires since some respondents misunderstood some options and gave their own answers, which later allowed the researcher to re-designate their answers correct categories.

5- The open-ended questions used in the questionnaire helps to give the respondents the respect and the feeling of contribution by giving them the chance to write their own answers and comments. This makes answering the questionnaire more enjoyable and encourages them to think and answer the questions more accurately.

6- An option for “I don’t know” answer was used for most questions to encourage those who were unsure about the question or their answer or to disagree with any of the given answers. Respondents use it rather than forcing them to give an inaccurate answer. All “I don’t know” answers were excluded from the analysis and considered as missing values since they add no information. Very few “I don’t know” and missing answers were found, which suggests that questions were clear enough and the respondents were willing to answer.

7- The respondents were given a brief description of the proposed MSUs, to clarify any misunderstanding from their previous experience with other trials or proposals to enable them to answer the questions properly. This brief description may have had some positive bias, but by using probable phrases rather than definite ones, the effect was reduced. This bias was reduced further given the natural tendency of people to reject change.

8- The question about their general opinion about the system of MSUs comes at the end of the questionnaire when the respondents have gained a good understanding of the different types of MSUs proposed and the possible hindering factors that may affect them. Respondents were well informed to give accurate answers.
The validity of the questionnaire that it had been answered by the respondent and not made-up by the students is assured by the following:

1- There was no motive for the student to make-up questionnaires since no minimum number of questionnaires was required. They were not required to wait for the respondent to answer the questionnaire or conduct lengthy interviews.

2- By continuous close supervision during data collection and by selecting experienced senior students that have previously conducted satisfactory work at the Institute.

3- The answers and comments to the open-ended questions confirmed that the questionnaires were answered by the service providers themselves because the style of the written comments, their arguments and their answers match the type of response the researcher would expect from experienced people in providing services for the Hajj and cannot be fabricated by the students who lack that experience.

4- The consistency of the answers for each questionnaire about demographical and service questions and their match with the knowledge of the researcher regarding the characteristic of the different sectors providing services for pilgrims confirms that service providers were reached.

The validity of the data entry and analysis is assured by the following:

1- The data entry facilities at the CTHMIHR are used for entering and checking data and the researcher double checked data files and compared them with the original questionnaires.

2- Labelling entry fields with names rather than numbers only to ensure placing each data entry in the right place. The analysis was made for the relevant data.

3- The tabular format for the questionnaire helped check data entry by avoiding mistaken answers introduced by unclear handwriting.

4- The total number of the returned questionnaires was 297 which is quite large and gives good statistical results.

Based on the procedures and the analysis mentioned above, it can be concluded that the data collected by the questionnaire are of high quality and confidence can be assured about their validity.
6.9 Closure

An approach to managing MSUs by scheduling is described and the potential for using Genetic algorithms to arrive at an optimum MSU schedule is highlighted. The MSU schedule will be used for preliminary planning of service for the Hajj and as a backup.

A 'Just In Time MSUs' (JIT MSUs) approach is suggested in this research through active online control of MSUs movements to provide services just in time, wherever needed. This achieves higher efficiency and utilization of MSUs resources.

Intelligent fuzzy logic controllers are used, in microscopic scale, to evaluate the situations at every zone and issues scores to reflect the degree of need to keep existing MSUs or the need for additional ones. Another fuzzy logic controller is used, by the control centre, to re-evaluate these requests for MSUs. This is made from a macroscopic point of view, in light of other conditions relating to the system as a whole.

Since zones are competing for limited resources, the control centre uses a specially written MATLAB function to sort these re-evaluated scores and issues orders according to their relative importance. Since all scores are relative to each other, the most important requests will appear at the top of the list and will be answered accordingly. Least needed MSUs will appear at the bottom of the list and will be returned if needed somewhere else. This evaluation process using relative scores was found to be very helpful in managing MSUs. It also makes the search for optimum settings for Fuzzy logic controllers not critical for this research as the same rules and MFs apply to all zones simultaneously.

Finally, the validation of the methodologies used for investigating the proposed system of MSUs was discussed.
CHAPTER SEVEN
Discussion of the Developed System of Mobile Service Units (MSUs)

7.1 An overview of Chapter Seven

The overall picture of the developed system of MSUs has been viewed from three different perspectives. In chapter 3, the system was investigated from the point of view of service providers. In chapter 4, the ability to make these MSUs and integrate them within the master plan was investigated. In Chapters 5 and 6, the general model for the system of MSU and the control of the system were developed.

In this chapter, these investigations are discussed and linked together and a general picture of the system is drawn to aid better understanding and recognition of the validity of the proposed system of MSUs. The discussion starts by examining the methodologies and instruments used for the investigation, which is then extended to the results and findings of these investigations. Afterwards, an overall picture of the proposed system of MSUs is drawn based on the findings of the research and some suggestions are made for further research. The chapter ends by highlighting the contribution of this research to knowledge.

The contents of Chapter Seven are organized as follows:

7.1 An Overview of Chapter Seven 7-1
7.2 Evaluation of simulation results 7-3
7.3 The proposed system of MSUs from the control point of view 7-9
  7.3.1 MSUs of very-high and high service capacity 7-9
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7.4 The system of MSUs from the point view of traffic conditions and the capacity of road network 7-20
7.5 The proposed system of MSUs from the economic point of view

7.5.1 The use of MSUs for other events
7.5.2 The economic parameters for the comparison between the fixed centres and the MSUs
7.5.3 Economic comparison between the fixed centre and its MSU equivalent
7.5.4 The Cost of over and under supply of services during the Hajj
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7.6.5 The general opinion of service providers regarding the system of MSUs

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7.7.2 Reservation of bus trips
7.7.3 The control centre for the shuttle buses
7.7.4 The Shuttle Buses
7.7.5 The control centre for MSUs
7.7.6 The MSUs
7.7.7 Serving pilgrims and assuring customers satisfaction
7.7.8 Implementation of the system of MSUs

7.8 The contribution of this research work to knowledge
7.2 Evaluation of simulation results

Different control settings were tested through simulation and a specially written function (RunModel3.m, Appendix D) was used to repeatedly change control settings (described previously in Chapter 6), run simulations and save results. This allowed conducting hundreds of lengthy simulation runs automatically.

The values for “Extra MSUs” represent the 100% of MSUs needed for one zone plus a percentage for the additional MSUs divided by 100 for simplification, e.g. a value of 130% is represented by 1.3. The values for “Extra MSUs” are initially set to [1.6 1.6 1.2 1.2 1.2 1.2 2.6 1.2 1.2 1.2 1.2 1.4 1.2 2.6 1.2] for service-groups 1 to 16 respectively and tested with 0.2 increments up to 0.6. The “Future Time Span” represents the time interval that the control looks ahead to consider the expected futuristic situations and was tested for 0.5 and 1 hr.

The control settings shown in Figure 6.28 of Chapter 6 were tested for different values. The “Minimum Acceptance Score” (MAS), that represents a value below which the request for MSUs will not be considered, is tested for scores from 3 to 4 in 0.2 increments. The “Maximum Return Score”, that represents the lowest (-ve) score above which a request to return MSUs will not be considered, is tested for values equal to the [-MAS to -4] in -0.2 increments. These settings gave a total of 168 simulation runs. The range for these settings are selected based on experience gained from previous simulation runs and are expected to cover the range of acceptable results.

In order to evaluate the results of these runs, data was collected and saved in separate files recording service status, maximum number of MSUs used and orders to send and return MSUs. Data for periods of under and over supplies were collected using enabled subsystems that detect changes in service status.

The process of evaluation of simulation runs is based on multiple stages. In the first stage, the number of unstable orders is used as a filter to reject any control setting that causes unstable MSU-orders. Instability of MSU-orders is considered to occur, as described before in Chapter 6, when an order is issued to send an MSU to a
particular zone in one evaluation cycle, then a contradicting order to release an MSU of the same type is issued within the next 10 evaluation cycles (4 hr) or vice versa. The time of 4 hr is assumed sufficient for commercial MSU operators to earn some money before being assigned new serving jobs. Shorter serving times may cause inconvenient to them, as they need to travel more frequently. It also generates more trips that increases traffic volume. However, the minimum time for serving jobs can be adjusted and approved by officials and service providers when planning for services for the Hajj.

A specially written function (OrdersFluctCounts1, Appendix D) counts these unstable MSU orders and if an unstable order is detected, the run is considered unstable and excluded from the evaluation. Therefore, only stable runs are considered for further evaluation. It is found that not all control settings can provide stability for all types of MSUs at the same time (Table 7.1). This is due to the high variation in MSUs’ service capacities, ranging from 13.4k to 200k inhabitants. An appropriate setting for MSUs of low service capacity is not necessarily suitable for MSUs of high service capacity. Therefore, each MSU service-group is evaluated individually to find its best control settings. When operational, the control centre will use the best relevant control settings for every MSU-group under evaluation.

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<tr>
<th>Group</th>
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<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity (inhabitants) (PU)</td>
<td>100k</td>
<td>100k</td>
<td>22k</td>
<td>2k</td>
<td>50k</td>
<td>20k</td>
<td>25k</td>
<td>200k</td>
<td>13.4k</td>
<td>16.7k</td>
<td>20k</td>
<td>20k</td>
<td>100k</td>
<td>15.4k</td>
<td>200k</td>
<td>50k</td>
</tr>
<tr>
<td>Stable Runs (out of 168)</td>
<td>168</td>
<td>168</td>
<td>64</td>
<td>168</td>
<td>168</td>
<td>168</td>
<td>168</td>
<td>18</td>
<td>49</td>
<td>163</td>
<td>13</td>
<td>8</td>
<td>36</td>
<td>10</td>
<td>168</td>
<td>16</td>
</tr>
</tbody>
</table>

During the second stage, statistics are calculated, for each service, for every run, using a specially written function (StatusStatisticsAll2, Appendix D). Statistics include: the mean of service status, the standard deviation of service status, the period of minimum under-supply, sum of under-supply periods, sum of over-supply periods, and the maximum number of MSUs used (Table 7.2). These statistics are
selected to represent some important issues for determining the suitable settings for controlling MSUs.

The value of the "Mean Service Status" reflects the overall average of service status for a particular service group at all zones. In the ideal case the mean should be almost zero to reflect that no over or under supply has occurred or they are equally balanced. Therefore, the control should aim to shift the Mean of service status value toward zero. The closer the value of the mean of service status to zero the better the level of services provided, hence, the better the control settings.

The value of the "Standard Deviation of Service Status" reflects the dispersity of over and under supply periods. The closer its value to zero, the better the level of service achieved, since there is no much deviation between under and over supplies periods.

The value of the "Worst Under-supply Period" reflects the worst incident of shortage of service occurring during simulation. Therefore, the lower the shortage of service, the better service level provided. The "Sum of Under-supply Periods" reflects the accumulated shortage of service provided. Therefore, one of the objectives of the control should be to minimize its value.

The value of "Sum of Over-supply Periods" is used to reflect the capacity of services provided but not used. This causes economic loss to service providers as they provide more services than needed. The aim of the control should include minimizing this value for better efficiency.

The value of "Maximum Number of MSUs Used" reflects the MSU resources needed to achieve an acceptable level of service. Reducing the number of MSUs used reduces the capital cost of the system and is considered to be one of the main objectives of using MSUs.

During the third evaluation stage, the previous statistics are used to compare all runs using a fuzzy logic controller for each measure, embedded in a specially written function (FzzyEvaluateRuns.m, Appendix D). The evaluation is made for every
service in every run and the calculated fuzzy score is recorded. These scores give the "goodness" of each setting relative to others.

During the fourth stage, runs with maximum and minimum scores are identified. If two or more runs have the same score, the earlier is selected to reflect least setting values.

Finally, graphs for the highest scores are plotted, compared and evaluated visually. If an un-preferred behaviour such as short interval between sending and returning MSU or long periods of under or over supply are observed, the next highest score is plotted and evaluated, and so on, until the best response is found.

The statistics and evaluation results for the best control settings are listed in Table C1, Appendix C for all MSUs-groups and Table 7.2 for selected MSUs of different service capacity. To recognize the improvements, these statistics can be compared with the statistics and results for the worst control settings listed in Table C2, appendix C for all MSUs and in Table 7.3 for the selected MSUs.

It can be concluded that a wide spectrum of possible control settings for the different MSUs, are tested by a large number of simulation runs and the outcomes are evaluated quantitatively in order to select the most appropriate control settings that satisfies the interests of service providers and customers.
Table 7.2: Statistics and evaluation of simulation results for selected MSUs-groups at their best stable control settings

<table>
<thead>
<tr>
<th>MSU-group</th>
<th>8 (4000)</th>
<th>13 (2000)</th>
<th>4 (1333)</th>
<th>5 (1000)</th>
<th>7 (500)</th>
<th>9 (267)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(100%)</td>
<td>(50%)</td>
<td>(33%)</td>
<td>(25%)</td>
<td>(12.5%)</td>
<td>(6.7%)</td>
</tr>
<tr>
<td>(Service Capacity in PU)</td>
<td>(200k)</td>
<td>(100k)</td>
<td>(66.7k)</td>
<td>(50k)</td>
<td>(25k)</td>
<td>(13.3k)</td>
</tr>
<tr>
<td>(Service Capacity %)</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
<td>(6)</td>
</tr>
<tr>
<td>(Capacity in inhabitants)</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
<td>(6)</td>
</tr>
<tr>
<td>(MSUs for 100% population/zone)</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
<td>(6)</td>
</tr>
<tr>
<td>Run Number</td>
<td>33</td>
<td>118</td>
<td>127</td>
<td>133</td>
<td>111</td>
<td>60</td>
</tr>
<tr>
<td>Future Time Span</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>20</td>
<td>40</td>
<td>20</td>
</tr>
<tr>
<td>Min. Acceptance Score</td>
<td>3.2</td>
<td>3.4</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>3.6</td>
</tr>
<tr>
<td>Max. Return Score</td>
<td>-4</td>
<td>-3.4</td>
<td>-4</td>
<td>-4</td>
<td>-3.8</td>
<td>-3.8</td>
</tr>
<tr>
<td>Max MSUs used (per 4 zones)</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>16</td>
<td>32</td>
<td>60</td>
</tr>
<tr>
<td>Additional MSUs</td>
<td>200%</td>
<td>50%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Service Status Fluctuations</td>
<td>11</td>
<td>19</td>
<td>38</td>
<td>57</td>
<td>85</td>
<td>106</td>
</tr>
<tr>
<td>Mean Service Status (inhabitant.hr)</td>
<td>665</td>
<td>287</td>
<td>-5.4</td>
<td>-6.1</td>
<td>-9.4</td>
<td>-5.9</td>
</tr>
<tr>
<td>Standard Deviation (inhabitant.hr)</td>
<td>956</td>
<td>576</td>
<td>178</td>
<td>149</td>
<td>207</td>
<td>302</td>
</tr>
<tr>
<td>Worst Under Supply (inhabitant.hr)</td>
<td>-48</td>
<td>-170</td>
<td>-520</td>
<td>-621</td>
<td>-868</td>
<td>-1977</td>
</tr>
<tr>
<td>Zone of Worst Und-supply</td>
<td>111</td>
<td>111</td>
<td>111</td>
<td>111</td>
<td>111</td>
<td>311</td>
</tr>
<tr>
<td>Total Under supply (inhabitant.hr)</td>
<td>-110</td>
<td>-560</td>
<td>-2444</td>
<td>-2539</td>
<td>-4738</td>
<td>-6266</td>
</tr>
<tr>
<td>Maximum Over-supply (inhabitant.hr)</td>
<td>2750</td>
<td>2086</td>
<td>488</td>
<td>586</td>
<td>522</td>
<td>1742</td>
</tr>
<tr>
<td>Zone of max Over-supply</td>
<td>111</td>
<td>111</td>
<td>211</td>
<td>211</td>
<td>111</td>
<td>411</td>
</tr>
<tr>
<td>Total Over supply (inhabitant.hr)</td>
<td>7424</td>
<td>6019</td>
<td>2238</td>
<td>2187</td>
<td>3941</td>
<td>5648</td>
</tr>
<tr>
<td>Fuzzy Evaluation Score</td>
<td>591</td>
<td>613</td>
<td>618</td>
<td>628</td>
<td>634</td>
<td>643</td>
</tr>
</tbody>
</table>
Table 7.3: Statistics and evaluation of simulation results for selected MSUs-groups at their worst stable control settings

<table>
<thead>
<tr>
<th>MSU-group (Service Capacity in PU)</th>
<th>8 (4000)</th>
<th>13 (2000)</th>
<th>4 (1333)</th>
<th>5 (1000)</th>
<th>7 (500)</th>
<th>9 (257)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Service Capacity %)</td>
<td>(100%)</td>
<td>(50%)</td>
<td>(33%)</td>
<td>(25%)</td>
<td>(12.5%)</td>
<td>(6.7%)</td>
</tr>
<tr>
<td>(Capacity in inhabitants)</td>
<td>(200k)</td>
<td>(100k)</td>
<td>(66,7k)</td>
<td>(50k)</td>
<td>(25k)</td>
<td>(13,3k)</td>
</tr>
<tr>
<td>(MSUs for 100% population / zone)</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(8)</td>
<td>(15)</td>
</tr>
<tr>
<td>Run Number</td>
<td>137</td>
<td>110</td>
<td>28</td>
<td>169</td>
<td>167</td>
<td>75</td>
</tr>
<tr>
<td>Future Time Span</td>
<td>20</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Min. Acceptance Score</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Max. Return Score</td>
<td>-4</td>
<td>-4</td>
<td>-4</td>
<td>-4</td>
<td>-4</td>
<td>-4</td>
</tr>
<tr>
<td>Max MSUs used (per 4 zones)</td>
<td>16</td>
<td>12</td>
<td>12</td>
<td>16</td>
<td>32</td>
<td>60</td>
</tr>
<tr>
<td>Additional MSUs</td>
<td>300%</td>
<td>50%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Service Status Fluctuations</td>
<td>7</td>
<td>17</td>
<td>32</td>
<td>47</td>
<td>75</td>
<td>105</td>
</tr>
<tr>
<td>Mean Service Status (inhabitants.hr)</td>
<td>1845</td>
<td>406</td>
<td>-10</td>
<td>-7.5</td>
<td>-20</td>
<td>-10</td>
</tr>
<tr>
<td>Standard Deviation (inhabitants.hr)</td>
<td>2379</td>
<td>801</td>
<td>256</td>
<td>190</td>
<td>319</td>
<td>328</td>
</tr>
<tr>
<td>Worst Under Supply (inhabitants.hr)</td>
<td>-73</td>
<td>-415</td>
<td>-921</td>
<td>-619</td>
<td>-1745</td>
<td>-2316</td>
</tr>
<tr>
<td>Zone of Worst Under-supply</td>
<td>311</td>
<td>111</td>
<td>111</td>
<td>111</td>
<td>311</td>
<td>311</td>
</tr>
<tr>
<td>Total Under-supply (inhabitants.hr)</td>
<td>-100</td>
<td>-781</td>
<td>-2648</td>
<td>-2834</td>
<td>-5784</td>
<td>-6585</td>
</tr>
<tr>
<td>Maximum Over-supply (inhabitants.hr)</td>
<td>5163</td>
<td>2388</td>
<td>705</td>
<td>585</td>
<td>1059</td>
<td>1758</td>
</tr>
<tr>
<td>Zone of max Over-supply</td>
<td>411</td>
<td>211</td>
<td>211</td>
<td>211</td>
<td>211</td>
<td>411</td>
</tr>
<tr>
<td>Total Over supply (inhabitants.hr)</td>
<td>13011</td>
<td>7678</td>
<td>2311</td>
<td>2503</td>
<td>4288</td>
<td>5474</td>
</tr>
<tr>
<td>Fuzzy Evaluation Score</td>
<td>426</td>
<td>424</td>
<td>366</td>
<td>436</td>
<td>414</td>
<td>408</td>
</tr>
</tbody>
</table>
7.3 The proposed system of MSUs from the control point of view

The discussion of the proposed system of MSUs from the control point of view will be based on the simulation results for the best response of the system to the changing demands for services. By sending MSUs of various service capacities namely: MSUs of very-high and high service capacity, MSUs of medium service capacity and MSUs of low and very-low service capacity. One type of MSU will be selected from each group for discussion. Similar discussion can be extended to other MSUs-groups, for which graphs are presented in Appendix B.

7.3.1 MSUs of very-high and high service capacity

MSUs of very high service capacity of 200k inhabitants (100% of population of a zone), such as MSUs-group-8, require only one unit to serve the whole population of one zone. Therefore, it is either provided to a zone or not. When it is sent to a zone, it fulfils all its need for that service whatever the population level. However, for low population, the unused service capacity for that unit is reflected as periods of oversupply of service (Figure 7.1, points 1, 2, 4 and 5). On the other hand, if that MSU is removed, the shortage appears as periods of under supply even for low population levels (Figure 7.1, point 3).

Figure 7.1 represents the response of the control due to the selected best settings for MSUs-group-8 presented in Table 7.2. Figure 7.2 shows the response of the control due to the worst settings presented in Table 7.3 for the same group.

It can be seen that the additional MSUs needed in the best response is 200% compared to 300% for the worst response. This reduction in MSUs is due to release of MSUs from zone-111 to serve zone-311 (Figure 7.1). This compares with no release of MSU from zone-111 (Figure 7.2), where an additional MSU was needed for zone-311. It can be seen (Figure 7.1, point-4), that although the first peak of zone-211 reaches less than 100k inhabitants, or half the capacity of one MSUs of group-8, an MSU was needed to cover that need since its absence will create severe shortage of service. This explains the need for the 200% of additional MSUs (total of three very high-capacity MSUs per zone) at best. In the worst case (Figure 7.2),
four MSUs are needed, one for each zone, which is equivalent to the case of using fixed service centres.

Comparing the best and the worst control settings for MSUs-group-8, the proper response of the control in order to fulfil demand for services can be seen in graphs for the best settings (Figure 7.1). For the worst settings (Figure 7.2), wrong orders are issued for an additional unjustified MSU (point-1), or very late return of unneeded MSUs (points 2 and 3) and most seriously, late response for an urgent demand, which causes a severe shortage for the service (point-4).

Figure 7.1: Response of the control using the best settings for MSU-group-8
MSUs of high-service-capacity of 100k inhabitants (50% of max population of a zone), such as MSUs-group-13, are found to give better results compared with MSUs of very-high-capacity such as MSUs-group-8 discussed above. Table 7.2, represents these improvements in terms of less over supply, lower values for mean and standard deviations and most importantly in the reduction of the additional MSUs from 200% to 50%.

Comparing the graphs of the best and the worst control settings for MSUs-group-13 (Figures 7.3 and 7.4, respectively) it can be seen that with the best settings, the control responds properly for service demands at the four zones. For the worst control settings, the control sends MSU to zone-111 unnecessarily (Figure 7.4, point-1) and delays returning an un-needed MSU from zone-211 (point-2).

It can be concluded that using very-high-capacity MSUs does not provide much reduction in resources for the Hajj compared with fixed services centres, apart from the ability of using these MSUs somewhere else outside the Hajj. This draw back is improved by reducing the capacity of the services, hence giving more flexibility to respond to the variable demand for services.
Figure 7.3: Response of the control using the best settings for MSU-group-13

Figure 7.4: Response of the control using the worst settings for MSU-group-13
7.3.2 MSUs of medium service-capacity

MSUs of medium service capacity, such as MSUs-group-4, that have service capacity of 66.7k inhabitants (33% of population of a zone), show better results (Figure 7.5) compared with high and very-high-capacity MSUs (Figures 7.1 and 7.3) as discussed before. Although the minimum under-supply is worse, the mean of service status and standard deviation are reduced dramatically reflecting a better homogeneous response for the control (Table 7.2). The total under-supply of (-2,444 inhabitant.hr) is worse than those of high and very high capacity MSUs but still acceptable relative to the total service capacity of up to 11.2m inhabitant.hr for the same 7 days period for MSU-group-4. The most important improvement is that no additional MSUs (0%) are needed compared with (50% and 300%) for high and very-high-capacity MSUs respectively. This represents higher efficiency and utilization of MSUs for the Hajj.

The serial numbers at the start and ends of supply curves in figure 7.5 represent the serial number of the MSU serving that job. It can be seen that the total number of MSUs-group-4 used to serve zones 111, 211, 311 and 411 is only 3. Each covers 1/3 of the maximum population of a zone and no additional MSU is needed (0%). Initially the three units are with pilgrims in zone 111 and start leaving that zone gradually when pilgrims start moving from zone-111 to zone-211 between simulation steps 440 to 1400 (Day-7, hr-11 to day-8, hr-11). The first returned unit, MSU1, is sent to zone-211 at simulation-step 800 to serve pilgrims there and then onto zone 411. The second and third returned units, MSU2 and MSU3, are sent directly to zone-411 at simulation-steps 1650 and 2400 respectively to serve pilgrims that have just left zone-111 to zone-411 and so on as indicated in Figure 7.5.
Figure 7.5: Response of the control using the best settings for MSU-group-4

Figure 7.6: Response of the control using the worst settings for MSU-group-4
Another medium size MSU to be discussed is MSU-group-5. This group has a service capacity of 50k inhabitants (25% of population). Figure 7.7 shows the response of the control to the demand for service of MSUs-group-5. By comparing this figure with Figure 7.6 for MSUs-group-4, it can be seen that the response is improved as supply curves better match demand curves at zones 111, 211 and 411. This is due to the lower service capacity of MSUs-group-5, which gives the control 4 units of MSUs-group-5 to manipulate instead of 3 units of MSUs-group-4. Only at zone-311, MSUs-group-5 show a region of under-supply (Fig 7.7, point-1). This shortage is due to the low amount of extra demand that would not justify sending an additional MSU-group-5, whereas in the case of MSU-group-4 the extra demand is already satisfied by the higher service capacity of this group.

Comparing the best and the worst settings for groups-5 (Tables 7.2 and 7.3, and Figures 7.7 and 7.8 respectively), it can be seen that the results are very close and the gap between the best and the worst settings are very small. Moreover, from Table 7.1, it can be seen that all runs for group-5 result in stable orders. Therefore, this group achieves good results and stability for all control settings tested.

![Graphs of MSU supply and demand for different zones and services](image)

*Figure 7.7: Response of the control using the best settings for MSU-group 5*
7.3.3 MSUs of low and very-low service capacity

Figure 7.9 represents the response of control to the demand for MSUs-group-7. This group has a low service capacity of 25k inhabitants (12.5% of max population) therefore, eight units are needed to satisfy the maximum population of any zone. From the figure, it can be seen that the supply curve is a better match to the demand curve, compared with high capacity MSUs, especially for low demand peaks (Figure 7.9, points 1 and 2). However, some delay of the response is noticed at the beginning of the demand curve of zone-311 (Figure 7.9, point-3). This results in some shortage of service at that time. This delay is cased by the high traffic volume of buses transporting pilgrims from zone-411 to zone-311 at that time. Since this group has low service capacity, a high number of MSUs are needed to satisfy the increasing demand; therefore, not all requests are approved due to traffic volume limitations. Comparing the graphs of best and worst control settings for group-7, it can be seen that for the worst setting, a low demand is not satisfied at zone-111 (Figure 7.10, point-1) whereas a severe shortage of service occurs at zone-311 (Figure 7.10, point-2). These two defects are solved using the best control settings as shown in Figure 7.9.
Figure 7.9: Response of the control using the best settings for MSU-group-7

Figure 7.10: Response of the control using the worst settings for MSU-group-7
MSUs-group-9 has very low service capacity of only 13.3k inhabitants (6.7 % of max population). It was expected that such low service capacity would provide control with high flexibility to match any low variation in demand. This will be true if the control can send any number of MSUs at any time. However, due to traffic limitations, not all requests for MSUs can be answered. Figure 7.11 shows a good match between demand for service and MSUs supply to most zones, except at zone-311 where the delay in sending enough MSUs results in severe shortage of service for a relatively long time (Figure 7.11, point-2). Delay occurs also in releasing unneeded MSUs from zone-411 (Figure 7.11, point-1), even though they were badly needed for zone-311, due to the high traffic volume at that time.

Very-low-capacity MSUs shows some delayed response to the demand in Zone 311, Muzdalifah (Figures 7.9 and 7.11 for service groups 7 and 9) due to traffic volume limitation. The rise of the peak at Muzdalifah occurs due to the massive movement of pilgrims from Arafat to Muzdalifah after sunset of day-9 until mid night (simulation steps 2500-3000). During this period, a huge number of bus trips occur therefore not much room is left for MSUs movements.

High and medium-capacity MSUs are few in number, therefore, they have a better chance to be approved by the control to move to another locations during peak times. Low capacity MSUs are numerous and not all requests can be approved due to their exaggerated contribution to higher traffic volume.
Figure 7.11: Response of the control using the best settings for MSU-group-9

Figure 7.12: Response of the control using the worst settings for MSU-group-9
7.4 The system of MSUs from the point of view of traffic conditions and the capacity of the road network

Simulation results show that the additional traffic due to the movements of MSUs can be controlled and limited to less than the maximum road capacity of 750 Large Vehicles/hr/lane, which is equal to 75 LV/simulation step on the main loop. The control always gives priority to bus traffic to prevent any delay to critical movements of pilgrims and only the excess road capacity is utilised to move essential MSUs. Figure 7.13–a shows that if no control is applied, traffic volume will exceed the limit on many occasions causing traffic jams. Figure 7.13–b shows the success of the control in limiting the total traffic volume to less than the limit at all times. This assures that traffic will run smoothly without traffic jams or overflow.

This control is achieved in three stages. First the control sends buses according to the event program as long as their number does not exceed the limit. Otherwise, it sends the maximum number of buses in the current simulation step and sends the remaining in the next simulation step (Figure 5.16 of Chapter 5). Second, the Fuzzy Logic controller is used to re-evaluate requests for MSUs, as described before in Chapter 6, takes into consideration the expected traffic volume of buses at the current time and in the near future. This is to advice whether a request for an MSU should be approved at the current time or later. In the third stage, the control stops sending MSUs when the traffic volume limit is reached as described before.
Moreover, the total number of MSUs for the six loops of the master plan may not exceed 3500 units, which is about 19.4% of the total number of 18,000 buses to be used in the master plan (Beeah, 1999). The total number of trips generated by MSUs for the whole simulation (calculated from orders to send MSUs for the best control settings) is 30,049 trips. Compared with the total number of bus trips of 110,400 for the same period (calculated from population curves); MSUs trips are 21% of bus trips. Roughly speaking, on average there will be one MSU for every 4 buses on the road. The ratio of buses will increase during peak hours to transport pilgrims, whereas the ratio of MSUs will increase at off peak times. Furthermore, the total number of MSUs will be reduced if some services are grouped together (Multi-services-MSUs) and the capacities of small and very small MSUs are increased, which reduces the ratio of MSUs further.

It can be concluded that the system of MSUs will not affect the programs for transporting pilgrims during the Hajj as it will make use of the unused capacity of the road during off peak times.

### 7.5 The proposed system of MSUs from the economic point of view

The economic comparison between the alternatives of providing fixed service centres and the proposed MSUs can be highlighted from different perspectives as will be discussed in the following sections.

#### 7.5.1 The use of MSUs for other events

Being mobile, MSUs are not limited to work in a fixed place nor limited to specific seasons or events. Some of the uses are:

1- In the city of Makkah during the “Umrah” season where hundreds of thousands of visitors come to the Grand Mosque of Makkah “Almsjed Al-Haram”. Some of the possible usages are:

   a. In the central area around the Grand Mosque where the demand for services exceeds the capacity of the existing services.
b. At the major “Park and Ride” car parking inside and outside Makkah where tens of thousands of car users need to be served.
c. Near the main central bus stations.
d. In dedicated service parking areas near to large apartment buildings and accommodation complexes operating during Ramadan.
e. In selected services parks on the highways leading to Makkah to provide services to the large number of car travellers during Ramadan season.

2- In the city of Al-Madinah to serve hundreds of thousands of visitors to the Grand Mosque of Al-Madinah during that season in a manner similar to the case of Makkah.

3- In the city of Al-Madinah before and after the Hajj where most pilgrims arrange a visit to Al-Madinah before or after performing the Hajj. This generates peaks of demand for services similar, to some extent, to those of the Hajj.

4- In the nearby recreational and tourism areas on the West coast and the Southern part of Saudi Arabia where many visitors take their holidays especially during summer and school vacations.

5- In villages and suburban areas where the existing services and facilities need to be expanded, provided that they are not affected much when MSUs are withdrawn for about two weeks for the Hajj.

6- For other national and international events.

7- As a national reserve for emergency or disaster relief. From this perspective the government could participate towards the cost of the MSUs in terms of subsidies or hire contracts (Othman, 1992).

It can be concluded that there are many additional working days for MSUs to work beside the Hajj. This generates more income compared with the fixed service centres.
7.5.2 The economic parameters for comparison between the fixed centres and the MSUs

In order to compare between the alternative of providing fixed service centres and the alternative of providing the proposed MSUs from an economical point of view, different economical parameters are considered and simulated for a wide range of possible costing scenarios for a fixed service centre and its MSU equivalent. The assumptions made for the comparison are:

1- The MSU could cost more to build, compared with the fixed centre, if a specially made MSU is required. The MSU could cost less to build if a recycled bus is used.

2- The fixed centre and the MSU generate the same daily income during the Hajj since both provide the same service.

3- The running costs of the MSU could be more than that of the fixed centre due to its frequent movement, frequent reinstallation and less working space.

4- The MSU could work more days every year due to its capability to work outside the Hajj on other events and locations.

5- The service life for the MSU could be less than that of the fixed centre, due to its mobility and additional working days throughout the year.

For the sake of the economic comparison and since no specific costing figures are available for the wide variety of the proposed MSUs, relative values are used rather than specific numbers to investigate the relative economic improvements for the MSU over the fixed centre or vice versa. Therefore, the comparison is chosen relative to the initial capital cost of constructing one service centre for the service under investigation. Table 7.4 shows the parameters used for the economic comparison and the values used for simulation. The description of these parameters and setting of their values are given in the proceeding sections.
Table 7.4: Some parameters for economic comparison between Fixed service centres and their equivalent MSUs

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Fixed Service Centres</th>
<th>MSUs</th>
<th>Values used for simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of service units/centres</td>
<td>$4N_{fix}$</td>
<td>$1.1N_{fix}$</td>
<td>$N_{fix} = 1$</td>
</tr>
<tr>
<td>Initial capital cost of one unit</td>
<td>$C_{fix}$</td>
<td>$C_{MSU} \cdot C_{fix}$</td>
<td>$C_{fix} = -100%$</td>
</tr>
<tr>
<td>Total initial capital cost</td>
<td>$4N_{fix} \cdot C_{fix}$</td>
<td>$1.1N_{fix} \cdot C_{MSU} \cdot C_{fix}$</td>
<td>$C_{MSU} = 0.5, 1, 1.5 \text{ and } 2$</td>
</tr>
<tr>
<td>Annual working days</td>
<td>$D_{fix}$</td>
<td>$D_{MSU} \cdot D_{fix}$</td>
<td>$D_{fix} = 5$</td>
</tr>
<tr>
<td>Daily income</td>
<td>$I_{daily} = 0.02</td>
<td>C_{fix}</td>
<td>$</td>
</tr>
<tr>
<td>Running cost</td>
<td>$R_{fix}$</td>
<td>$R_{MSU} \cdot R_{fix}$</td>
<td>$R_{fix} = 1$, $1.25$, $1.5$, $1.75$, and $2$</td>
</tr>
<tr>
<td>Daily profit</td>
<td>$I_{daily} - R_{fix}$</td>
<td>$I_{daily} - (R_{MSU} \cdot R_{fix})$</td>
<td>As above</td>
</tr>
<tr>
<td>Net annual profit</td>
<td>$(I_{daily} - R_{fix}) \cdot D_{fix}$</td>
<td>$(I_{daily} - (R_{MSU} \cdot R_{fix})) \cdot (D_{MSU} \cdot D_{fix})$</td>
<td>As above</td>
</tr>
<tr>
<td>Service live</td>
<td>30 years</td>
<td>30 $\cdot L_{MSU}$</td>
<td>$L_{MSU} = 0.4, 0.6$ and $0.8$</td>
</tr>
</tbody>
</table>

Where:
- $N_{fix}$: the number of fixed centres of a particular service
- $C_{fix}$: the initial capital cost of constructing one fixed service centre
- $C_{MSU}$: the initial capital cost of one MSU relative to that of the fixed centre
- $D_{fix}$: the annual working days for a fixed service centre
- $D_{MSU}$: the ratio of annual working days of the MSU to that of the fixed service centre
- $I_{daily}$: the daily income for the fixed centre or its MSU equivalent
- $R_{fix}$: the running cost of the fixed centre per working day
- $R_{MSU}$: the ratio of the running cost of the MSU per working day to that of the fixed centre
- $L_{MSU}$: the service life of the MSU relative to that of the fixed centre

The total number of service units required:

In the case of the fixed service centres, all services have to be repeated at the four pilgrimage cities giving a total of 4-folds of the number of centres needed for one city. On the other hand, simulation results show that no additional MSUs are needed (as discussed before if all MSUs are of medium to low service capacity). In other words, the MSUs provided for one city will be enough to serve the other three cities. However, an additional 10% MSUs is suggested as a reserve; to give the control centre more flexibility to respond to urgent requests; to relief tight MSU schedule if
any and to replace broken MSUs if needed. Therefore, it can be said that on average there will be 1.1 MSUs for every 4 fixed service centres. Table 7.4 shows that if the number of fixed centres, of a particular service, needed to serve one city is \( N_{\text{fix}} \), then the total number of fixed centres is \( 4 N_{\text{fix}} \) to serve the four cities and the total number of MSUs is \( 1.1 N_{\text{fix}} \) including the 10% MSU reserve.

**The initial capital cost:**

If the initial capital cost for constructing one fixed service centre is \( C_{\text{fix}} \) (currency units) then the cost of constructing an equivalent MSU will be \( C_{\text{MSU}} * C_{\text{fix}} \) (currency units) where \( C_{\text{MSU}} \) is the initial capital cost of the MSU relative to that of the fixed centre. \( C_{\text{MSU}} > 1 \) if the MSU costs more to make than constructing the fixed centre and \( C_{\text{MSU}} < 1 \) if it is cheaper to make the MSU. Specially made MSUs may cost more to build whereas recycling buses is a low-cost option for making MSUs. The total initial capital cost will be the product of the number of units and their cost. The capital cost of one fixed centre (\( C_{\text{fix}} \)) is set to–100%. Simulation is performed for the cases where the relative capital cost of the MSU (\( C_{\text{MSU}} \)) is 0.5, 1.0, 1.5 and 2 to that of the fixed centre (Table 7.4).

**The annual working days:**

The Hajj season lasts for about two weeks as a peak period and about a week before and after as low-peak period. Therefore it is reasonable to assume that an equivalent of about 20 working days can be achieved during the Hajj. These working days are shared between the repeated fixed centres in the four cities giving an annual working days total for the fixed service centre (\( D_{\text{fix}} \)) of 5 working days/fixed centre/year.

On the other hand the 1.1 MSUs (including the 10% reserve) may not achieve the 20 working days during the Hajj due to competition from the existing services in the city of Makkah. Therefore, it is reasonable to assume that a total of 14 working days for the 1.1 MSUs can be achieved during the Hajj. Moreover, it is reasonable to assume that the 1.1 MSUs could work, in various locations, an equivalent of 10 days during the Ramadan season and 20 days during vacations and holydays, giving an average of 40 working days/MSU/year or 8 times that of the fixed centre.
Table 7.4 shows that if the fixed centre could work for $D_{fix}$ days per year, then the equivalent MSU could work $D_{MSU} \times D_{fix}$ where $D_{MSU}$ is the ratio of the annual working days of the MSU to that of the fixed service centre. The simulation is performed for $D_{MSU} = 2, 4, 6$ and $8$ to cover scenarios when the MSU may just work for few days a year, much less than expected, to the 40 working days, as estimated above.

**The daily income:**

For every working day, the MSU or the fixed centre will generate an income either paid by customers or by the Hajj authorities. Since both will provide the same service, they should generate the same daily income of $I_{daily}$ (currency units). If more than one MSU is equivalent to the fixed centre, then they are considered as one batch, hence generating the same daily income.

In order to make the project profitable, the pay back period for the capital cost should not usually exceed 10 years, or an annual profit of 10% of the capital cost. However, since the fixed centres work very few days every year, such target is quite difficult to achieve without charging premium prices for the services. Therefore, it is suggested that the pay back period be extended to 20 years with governmental promotions, exemptions and subsidies to encourage the private sector to invest in such fixed service centres.

Since an average of 5 working-days for each fixed centre can be achieved per year as mentioned before, this requires a daily sales income of 2% of the capital cost to achieve the 20 years pay-back target (assuming that the running cost is 50% of sales). If this cannot be achieved as well, then it is assumed that the government will subsidize the difference. Table 7.4 shows that both the fixed centre and the MSU generate an income in sales ($I_{daily}$) of 0.02 $C_{fix}$ currency units per working day.

**The running cost:**

The running cost of the MSU is assumed to be more than that of the fixed centre, as mentioned before, due to the extra cost associated with the mobility of the MSU; fuel, maintenance, installation cost, insurance, tight working space, etc. Therefore, if
the running cost of the fixed centre per working day is $R_{fix}$ (currency units), then the running cost of the MSU per working day is $R_{MSU} \times R_{fix}$ (currency units), where $R_{MSU}$ is the ratio of the running costs of the MSU per working day to that of the fixed centre. Table 7.4 shows the running cost of the fixed centre and the MSU. The running cost $R_{fix}$ is set to 1 assuming that the running cost should not exceed 50% of the daily income $I_{daily}$ which was set to 2 as mentioned before. The simulation is set for $R_{MSU} = 1, 1.25, 1.5, 1.75$ and 2 to cover the scenarios were the running cost of the MSU is almost similar to that of the fixed centre, to the extreme were the MSU costs twice that of the fixed centre to run, hence the running cost is equivalent to the income, i.e. no profit is generated.

*The net annual profit:*

The net daily profit is the difference between the daily income and the daily running cost. Table 7.4 shows that for the fixed centre the net daily profit is $(I_{daily} - R_{fix})$ and for MSU the net daily profit is $(I_{daily} - (R_{MSU} \times R_{fix}))$ currency units. The net annual profit is the product of the net daily income multiplied by the total annual working days as shown in Table 7.4.

*The service life:*

Due to the mobile nature of the MSUs, the use of lightweight construction materials and the additional working days, it is reasonable to assume that the service life of the MSU is shorter than that of the fixed centre. The service life of the fixed centre is assumed to be 30 years and the service life of the MSU is $L_{MSU} \times 30$ where $L_{MSU}$ is the service life of the MSU relative to that of the fixed centre and $L_{MSU} < 1$. By the end of the service life of the fixed centre or the MSU the selling price of the unit is assumed to be zero and a new one is required. The simulation is made for the cases where the service life of the MSU ($L_{MSU}$) is 0.4, 0.6 and 0.8 of that of the fixed centre, as shown in Table 7.4.
7.5.3 Economic comparison between the fixed centre and its MSU equivalent

The economical parameters described in the previous section and presented before in Table 7.4 are simulated for different costing scenarios for comparison between the fixed service centre and its MSU equivalent. Figure 7.14 shows the cash flow for the MSU compared to that of the fixed service centre for these scenarios. The different curves shown in Figure 7.14 a, c and e, cover the cases where the service life of the MSU is 40%, 60% and 80% of that of the fixed centre, the capital cost of the MSU is 50%, 100%, 150% and 200% of that of the fixed centre, the running cost of the MSU is 100%, 125%, 150%, 175% and 200% of that of the fixed centre and the total annual working days of the MSU reaches 2, 4, 6 and 8 times of that of the fixed service centre. Therefore, the total number of cases presented in Figures 7.14 a, c and e is 240 scenarios.

For simplicity, these curves are reduced and presented in Figure 7.14, b, d and f, respectively, by showing the highest and the lowest value for each group of similar service life and initial capital cost. The horizontal curves (Figure 7.14, curves no. 6 to 9) show the cases where the price of the MSU service is set just to cover the running cost only (for non-profit organizations). The initial capital cost for the MSU and the cost of replacing it by the end of its service life is assumed to be paid by other means.

The cash flow for the fixed service centre (Figure 7.14, curve no. 10) shows no profit (-ve value) for the whole simulation period of 30 years. This is logical since the repeated 4 centres in the four cities work for just a few days every year. Moreover, by the end of the service life of the fixed service centre (30 years), a new centre is needed to replace the old one, which is shown as a severe drop in cash flow at the end of the simulation period (end of curve no.10, Figure 7.14). This indicates that fixed centres need to be heavily subsidised by the government or other means to construct and to operate. Most likely, commercial service providers, will not invest in these fixed service centres unless such subsidies are granted, or they limit themselves to invest in just a few locations that appear to be profitable and neglect the remaining non-profitable locations.
On the other hand, Figure 7.14 shows that, in most cases, the cash flow for the MSU achieves profit (+ve value) before the end of the comparison period despite non-optimistic costing scenarios. In all scenarios simulated, the cash flow status for the MSU is much better than that of the fixed service centre at the end of the 30 year comparison period, especially when adding the selling value of the remaining service life to the last MSU purchased. In the best scenario the balance reaches (+1123 %) for the case when the service life of the MSU is 80 % of that of the fixed centre. The initial capital cost is 50% that of the fixed centre. The running cost is the same as the fixed centre and the total annual working days is 8 times that of the fixed centre. For
the worst scenario simulated, when the MSU service is provided on a non-profit bases, the service life of the MSU is very short (40% of that of the fixed centre) and the initial capital cost is very high (double that of the fixed centre). Regardless of extra working days, the balance at the end of the 30 year period is (- 616 %), but still better than that of the fixed service centre which reaches (-650%) even though it charges double the price for the same service (operates on commercial bases) as shown in Figure 7.14.

Table 7.5 shows the cases where the MSU achieves profit (+ve cash status) at the end of the 30-year period. It can be seen that for most scenarios simulated, the MSU is profitable. Some of the cases shown in figure 7.14 a, c and e (The curves below the zero line) and not listed in Table 7.14 and are mainly for the cases the selling price of the service is just enough to cover the running cost for non-profit organizations.

It can be concluded that fixed service centres are not economically viable, whereas the MSUs are profitable, and the government need not to supply subsidies. They may charge the service providers for the infrastructure and apply fees to commercially operated MSUs.
Table 7.5: Return on Investment at the end of the 30 year comparison period for the MSU with different scenarios

<table>
<thead>
<tr>
<th>Service Life (Relative to the Fixed service)</th>
<th>Capital Cost (Relative to the Fixed service)</th>
<th>Running cost (Relative to the Fixed service)</th>
<th>Annual Working Days (Multiples of that of the Fixed service)</th>
<th>Return On Investment in 30 years (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.8</td>
<td>0.5</td>
<td>1.0</td>
<td>2 - 8</td>
<td>223 - 1123</td>
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<td>2 - 8</td>
<td>148 - 823</td>
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<td>2 - 8</td>
<td>73 - 523</td>
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<td></td>
<td>1.8</td>
<td>4 - 8</td>
<td>73 - 223</td>
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<td>1.0</td>
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<td>146 - 1046</td>
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<td>2 - 8</td>
<td>71 - 746</td>
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<td>4 - 6</td>
<td>146 - 446</td>
</tr>
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<td></td>
<td></td>
<td>1.8</td>
<td>6 - 8</td>
<td>71 - 146</td>
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<td>4 - 8</td>
<td>219 - 669</td>
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<td>6 - 8</td>
<td>59 - 284</td>
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7.5.4 The Cost of over and under supply of services during the Hajj

The "cost of over supply" of a service can be considered as the economic loss of opportunity for service providers as they provide more service than is consumed or sold. The "cost of under supply" can be considered as a penalty to be applied to service providers, as some customers are not served completely or wait to be served for long time. The total over and under supply for the different types of services provided by the MSUs is calculated and presented in Table C1, Appendix C.

Figure 7.15.a shows that no under supply penalty will be applied to the fixed service centre as it serves all of the customers. However, there is a huge over supply loss (the shaded area shown in Figure 7.15-a) since the population does not reach 100% most of the time, although 100% of service capacity was made available for the whole period. On the other hand, Figure 7.15.b shows that although under supply penalties are frequently applied to its equivalent MSUs in addition to some over supply losses, the total loss for the MSUs is much less than that of the fixed centres.

\[\text{Figure 7.15: Over and under supply of services (shaded area) compared with the actual demand for fixed centers and MSUs}\]
7.5.5 Creating a secondary market for reconditioned out of service buses, spare parts and maintenance

Out of the 44 types of services recommended by service providers as discussed before in Chapter 3, more than 30 services can be made using recycled buses, using one of the designs demonstrated in Chapter 4.

The number of recycled buses for each loop will be about 340 and for the six loops will be about 2040. This quantity of MSUs can be easily provided by buses that goes out of service. Since the total number of out of service buses is much more than that needed to be reconditioned as MSUs, service providers will have the opportunity to select buses of good condition at competitive price. The remaining buses form an abundant resource for spare parts. Therefore, it is expected that a local industry will be created for reconditioning these out-of-service buses to be used as MSUs, recycling buses for other purposes, exporting MSUs and local market for spare parts.

7.6 The proposed system of MSUs from the point view of service providers

7.6.1 The profile of the respondents

The profile of the 297 respondents for the survey conducted in Chapter 3 shows almost an equal representation for private and governmental sectors (50% and 48% respectively), and reflects the temporary nature of working during the Hajj since nearly half of the managers and supervisors (46%) only work temporarily for the Hajj. They are familiar with the pilgrimage areas and are closely in touch with the Hajj activities since the majority of them (more than 90%) are working in the Makkah region. Nearly half of the respondents (48%) have fieldwork and field supervision experience, while the rest have administrative and general supervision experience. About 2/3 of the respondents (65%) have very good experience of working during the Hajj for more than 6 times and many of their departments (43%) serve high number of pilgrims every day (more than 5000 pilgrims/day).
The high level of practical experience possessed by the respondents and their work in sectors that directly provide services for pilgrims is very important for this study as it gives more confidence about the validity of their answers, especially for rating the different aspects related to the concept of the MSUs.

7.6.2 The sufficiency of existing services

Based on the investigation conducted in Chapter 3, it was found that 12 types of services (out of 26) were provided by more than half of the respondents. In addition, it was noticed that most service providers provide more than one type of service. This can be explained by the finding that most service providers are responsible for quite a large number of pilgrims; hence, they need to provide them with a wide range of services. Moreover, very specialized service providers usually provide some complementary services to ensure success of their main service.

Out of the 26 types of services, service providers considered that no single service is ‘Not sufficient at all’, 18 services were considered ‘Sufficient’ and 8 services were considered ‘Not sufficient enough’. The 8 services that were considered ‘Not sufficient enough’ are not essential and can be considered as optional. It can be concluded that service providers are quite happy with the sufficiency of the current services provided during the Hajj.

7.6.3 The feasibility of the different types of MSUs proposed

It is found from the investigation conducted in Chapter 3 that out of the 59 types of MSUs listed, 44 types were considered by the respondents to be ‘Feasible’ and ‘Feasible very much’. Only 15 types of MSUs were not considered feasible enough. None of the proposed MSUs was rejected totally or considered ‘Not feasible at all’. The accepted 44 types of MSUs form the proposed system of MSUs that are modelled and tested in this research as described before. The remaining 15 types that are not yet considered feasible, but not rejected as well, can be considered later as an expansion to the system of MSUs once implemented and proved successful. This encourages more service providers to consider making their services mobile.
It can be concluded that the service providers contributed actively to determining the types of services they considered suitable to be developed as MSUs. This confirms the validity of the concept of MSUs form the point view of service providers.

7.6.4 The concerns of the service providers regarding the proposed system of MSUs

Eighteen possible factors that may hinder the implementation of the system of MSUs were listed and the respondents were asked to evaluate their impact. It was found that none of these factors was considered ‘Extremely hindering’, but also none were considered ‘Not hindering at all’. All of the 18 possible hindering factors were considered by the respondents to be somewhere between ‘Relatively not hindering’ and ‘Hindering slightly’ (Table 3.10). This intermediate level of hindering impact suggests that service providers consider these factors more like “concerns” that need to be well addressed and resolved before establishing the proposed MSUs rather than considering them as “threats” that may prevent establishing the system.

The highest concern, “Traffic jams on car roads”, is totally related to the existing conditions, where traffic jams are quite a phenomena during the Hajj. As mentioned before, the proposed system of MSUs is not intended to be established within the existing traffic system but rather to be integrated within the new master plan. Moreover, simulation results, as discussed before, showed that traffic volume can be managed and controlled to be within the capacity of the road networks of the master plan. Hence, the risk of traffic jams is reduced dramatically. Therefore, it can be said that the highest concern mentioned above and the 5th highest concern, which is ‘the network of exclusive bus roads’ are resolved.

The 2nd highest concern, “The cost of manufacturing the MSUs”, can be reduced dramatically by recycling out-of-service-buses, as demonstrated before. This can provide most of the MSUs needed and their spare parts. Specially made MSUs could be expensive, but the economic comparison (Table 7.5) shows that even if the capital cost of the MSU is double that of the fixed service centre, the MSU is more profitable in most cases. This is due to its mobility, which allows for reduction in its number and increase in its working days by working outside the Hajj period.
The 3\textsuperscript{rd} highest concern, "Manufacturing MSUs", is resolved throughout the investigation conducted in Chapter 4. This demonstrated that many manufactures already develop different types of mobile services. The technology needed for making MSUs is simple and available. Moreover, modular extension units as suggested before in Chapter 4 simplify converting buses to MSUs.

The 4\textsuperscript{th} concern, "the space available to park MSUs", is resolved through integrating MSUs parking with bus parking in the master plan and by confirming the validity of the modified designs through discussions conducted with the architect of the master plan as described before in Chapter 4.

The 6\textsuperscript{th} and the 7\textsuperscript{th} concerns are related to "the time available to prepare MSUs" and "the time available to transport MSUs", respectively. These two concerns are also resolved by considering them in the developed control. The results of the simulation, show that Just-In-Time MSUs are achievable and satisfactory capacity of services can be provided at all locations most of the time.

The 8\textsuperscript{th} and the 9\textsuperscript{th} concerns, "Crowded pedestrian walkways" and "The existing infrastructures", respectively, are related to the existing conditions and are already resolved by the master plan by providing wider pedestrian walkways that are isolated from the traffic and that take the existing infrastructure into consideration in the master plan.

The 10\textsuperscript{th} and the 11\textsuperscript{th} concerns relate to the storage and maintenance of the MSUs. This can be resolved by following some measures similar to the current procedures for storing and maintaining the large number of buses used for the Hajj. As mentioned before, out-of-service buses provide an abundant resource for spare parts for the reconditioned buses used as MSUs.

The remaining, less worrying concerns are mainly administrative and can be resolved easily by the gradual introduction of the MSUs and good coordination between the different stakeholders involved in providing services for the Hajj.
It can be concluded that the investigations conducted by this research have resolved the main concerns the service providers held and confirmed that the proposed system of MSUs can be implemented and operated successfully for the Hajj.

7.6.5 The general opinion of service providers regarding the system of MSUs

By the end of the questionnaire, as the respondents gained good understanding of the proposed system and its limitations, they were asked to give their general opinion regarding the proposed system of MSUs. It was found that (83%) are in favour of the concept, while only (17%) oppose the concept (Table 3.11). This result indicates the wide acceptance of the proposed MSU amongst managers and supervisors who are responsible for providing different types of services to pilgrims during the Hajj. This suggests that they are quite enthusiastic to see it implemented for the Hajj.

7.7 The overall picture of the proposed system of MSUs and suggestions for further studies

An overall picture of the developed system of MSUs can be drawn by integrating the different perspectives either investigated by this research, available with current technology and literature or suggested for further research and development. These perspectives will be discussed in the following sections.

7.7.1 The concept of JIT-MSU

The concept of Just-In-Time MSUs (Figure 7.16) suggested by this research, is based on an interactive response of MSU supply for the actual demand for services at the different locations of the Mega-event.

It worth mentioning that the apparent shortage of services at the beginning of the demand curves (Figures 7.5 and 7.7) may not contradict the concept of Just-In-Time MSUs for two reasons: 1) Newly arrived pilgrims will spend some time to settle down before they start looking for services, therefore the actual demand is less than population at that period. 2) A slight shortage of service supplies, relative to the total capacity of existing MSUs, may also not contradict JIT-MSUs, since the existing MSUs can operate above their nominal capacity for short periods to satisfy the
increased demand. This is usually acceptable in service industries since service providers can handle the additional demand for services and customers can accept to wait a bit longer to be served during peak times.

The JIT-MSUs and the Shuttle Bus services, mentioned before in Chapter 1 can be integrated through the following:

1- The representatives for pilgrims/visitors groups book their private bus trips to the required locations on-line, according to their preferred venue (Figure 7.16-1).

2- The Control Centre for the Shuttle Buses, at the support zone, processes these reservations, issues job orders to the Shuttle Buses and follows-up the transportation process (Figure 7.16-2). The Control Centre for the MSUs is notified of any updated bus schedules.

3- The Shuttle Buses transport pilgrims/visitors from one location to another, through the recommended route and then return back to the main support zone or to a local bus dispatch-parking zone. There they wait for the next transportation job (Figure 7.16-3).

4- The Control Centre for the MSUs evaluates the variable need for services at all zones and responds by issuing job orders to send MSUs, just-in-time, taking into consideration transportation time and other factors (Figure 7.16-4).

5- MSUs' operators receive job orders from the Control Centre and move their units to the new location accordingly, through the recommended route (Figure 7.16-5).

6- Once in place, MSUs provide the proper amount of services required by the current population. The level of service and customer satisfaction is monitored and corrective actions will be taken by the control centre if needed (Figure 7.16-5).
More discussion on these stages and some technologies that can be used or developed to achieve such an efficient JIT-MSUs and the Shuttle Buses service will be described in the following sections:

7.7.2 Reservation of bus trips

The representatives of the groups of pilgrims, or their group leaders will be given ID numbers and passwords to allow them to make booking for their bus trips during the Hajj. The booking process can be made by different medias. On-line reservation through the web will be the main preferred media. Representatives will be able to insert the details of the required bus trips, check the available time-slots for transportation and receive confirmations about approved reservations. Alternatively, they can make a reservation through local travel agents. Text messages and faxes can also be used for reservation. Calling the Reservation Centre should be limited to urgent requests.

Intelligent systems such as those developed by Adler and Blue (1998), Adamski and Turnau (1998), and Hsu and Wen (2000); can be developed and used as a smart booking for Shuttle Buses in order to satisfy both the needs of customers and bus operators.
The booking system for Shuttle Buses also has a very important role in reducing traffic jams and crowds in specific areas. In the current transportation systems, pilgrims or their managers have most of the control over their buses and they can move whenever and wherever they like. This causes frequent rush-hour peaks during the Hajj. By booking Shuttle Buses, the pilgrims will still have the chance to book their preferred time slot for transportation, but late comers may find themselves needing to select an alternative time-slots before or after peak times. This distributes travel peak-demands over longer period, which avoids traffic jams and allows for use of the Shuttle Buses and road networks more efficiently. Another very important benefit for booking bus trips relates to safety; by distributing travel peak over a wider time slot to avoid accumulation of crowd at dangerous levels.

7.7.3 The control centre for the shuttle buses

The Control Centre for the Shuttle Buses, located in the support zone (between Arafat and Muzdalifah), receives confirmed reservations about bus trips and generates schedules for the Shuttle Buses accordingly. Different technologies have been developed for managing and operating bus fleets. These can be adapted for the Shuttle Buses to operate efficiently.

The control of the Shuttle Buses is suggested for development based on a Geographical Information System (GIS), in order to benefit from its capabilities in managing large amounts of special data regarding the locations of bus stops, pilgrims apartments and camps, current locations of buses, and road network information (Figure 7.17). An automated route planner for the Shuttle Buses is suggested for development in order to recommend the best and the alternative routes for each bus to reach its destination and to avoid congested roads. Intelligent highway systems should provide the control with online data for traffic condition at each road section. Traffic simulation software should be used to predict the traffic conditions and identifying roads that approach their capacity and to avoid them hence preventing traffic congestions.
Due to the improved economics of the Shuttle Buses, as mentioned before in Chapter-1, only good quality buses will be selected for the Shuttle Buses service and these can be fitted with efficient exhaust systems for better protection of the environment. These Shuttle Buses will be equipped with GPS, tracking devices and navigations systems that will guide the driver through the route recommended by the Control Centre. Drivers will receive their job orders from the Control Centre through automated text messages and respond by driving the bus to its destination. Wireless communication and phone calls will be used for emergency and urgent requests.

Informative bus stations will be fitted with display screens, connected to the Control Centre. These will show the expected time remaining until the next bus. This allows the pilgrims of a particular group to gather and prepare themselves to get onboard, hence reducing the embarkation time. Such information is also useful if the bus will be delayed for any unexpected reason. This allows pilgrims to wait in a more convenient place rather than waiting patiently at bus station.

The main parking for the Shuttle Buses will be located in the support zone where the bulk of buses will be parked. Local dispatch bus parking in selected parts of Makkah will be used for fast response and to reduced travel time during the transportation stage from Makkah.
7.7.5 The control centre for MSUs

The Control Centre for the MSUs, at the support zone, evaluates the need for MSUs services due to the actual demand for services at every location. This is based on sensory systems and estimates the expected shift of demand for services due to the changing population at each location, based on bus schedules. It responds by making decisions and sending MSUs to satisfy these demands just-in-time. It takes transportation time and other factors into consideration. Back-up schedules will be made available to MSUs operators if needed. Therefore, the ultimate goal of the control is to obtain the right balance between demand and supply of services at different locations. Such balance would satisfy both the needs of customers for adequate and quality services, and the requirements of service providers in terms of utilization of their resources and good return on their investments.

The advances in Information Management, such as the work of Prinz (1996), Drew (1997) and Evers et al (2000), confirms that an advanced and reliable information management system for the MSUs can be developed and applied successfully. Of particular importance, is the work of Koshak and Flemming (2002) who demonstrated how data warehousing, combined with object-oriented data modelling was able to support decision-making that requires input from various heterogeneous data sources. Such data warehousing can provide the system of MSUs with detailed information about the type, quantity and time of service required taking into consideration the existing fixed services and infrastructure. It also provides valuable information about the customers expected to use these MSUs, hence allowing for service customisation.

Figure 7.18 shows a Control Screen schematic diagram for the system of MSUs. The control screen shows the current traffic volume at each section of the network and the population and the overall supply of services to each zone. Sub-windows allow the operator to observe the detailed supply of all MSUs services and to compare them with the actual demand for services at each zone.
Different techniques, described in the literature review, can be used for better estimation of demand for services from bus schedules and event's programs. The current population of a zone can be estimated from an automated counting system of buses entering and leaving a zone. The occupancy of the buses can be reported by the drivers as text messages. Infra-red cameras (Al-Habibeh et al 2003), can provide good estimation of crowd density and the number of customers in service areas online. Fuzzy logic controllers are found to be very effective in representing the logic of service providers and can be extended to represent the various stakeholders. Genetic algorithms are suggested for use when preparing MSUs back-up schedules.

7.7.6 The MSUs

The main parking for MSUs will be located at the support zone (between Arafat and Muzdalifah) and service parking will be located inside each zone as described before. MSUs operators receive their job orders by text messages, phone calls or from a local supervision office. Essential MSUs should be equipped with tracking devices to allow the control to follow up their movements. Navigator systems can assist drivers reach their destinations on time. MSUs can be modelled and tested by simulation to improve their operation.
MSUs of very-high service-capacity (200k inhabitants), that serve the whole population of a zone, are not recommended to be used in the proposed system of MSUs for the Hajj, for two reasons. The first is due to the small reduction in the number of units needed compared with fixed service centres, where on average, three-very-high-capacity MSUs will be needed for every four zones. This is close to the four centres in the case of using fixed service centres. Therefore, the reduction in the number of units is only –25% and may not justify the need for mobility of services unless needed somewhere else outside the Hajj. The second reason is from an operational point of view: Few spare MSU can be provided (otherwise this will reach the same number of fixed service centres), which means that there is no room for replacing broken MSUs. The solution to this problem is by using MSUs that provide multiple services for less numbers of people. In other words, increasing the number of units and by combining services together. By doing this, the total number of MSUs for these merged services will be reduced and their efficiency will be increased.

On the other hand, MSUs of very-low-service-capacity (less than 25k inhabitants), are not recommended due to other reasons. Although these MSUs provide high flexibility for the control to match small variations in demand for services, the high number of units required produces a high increase in traffic volume, which frequently exceeds road capacity. Therefore, to keep traffic volume below the maximum limit, not all requests for MSUs can be approved. This appears as a shortage of services provided. The solution to this problem can be achieved either by: increasing their service capacity to reduce their number by making use of external spaces, by increasing their efficiency, by improving their mobility which allows for a higher traffic volume or by a combination of these measures. If the service capacity of these MSU cannot be increased due to size or technical limitations, then some fixed service centres may need to be provided or additional MSUs brought in to serve as fixed services during the Hajj. These can be used somewhere else as mentioned before.

MSUs of medium to high service capacity ranging from 50k to 66.7k inhabitants (25% to 33% of population of a zone) are found to be very suitable for use in the
system of MSUs. They require no additional units and not much increase in traffic volume. Lower service capacity MSUs of 20k and 25k inhabitants are also suitable to some extent. They require no additional units and their performance can be improved by making use of external spaces in order to increase their service capacity, hence reducing the number of units.

7.7.7 Serving pilgrims and assuring customer satisfaction

The availability of services when needed could be one of the most important factors for customer satisfaction. If the demand for a particular service at a particular time exceeds the total supply of that service by a great proportion, the results are long queues and long waiting times that reduces the level of customer satisfaction. On the other hand, if supply exceeds demand by a great proportion, service providers satisfaction will be reduced as they provide services without enough customers. This may force them to increase the cost of their services. This in turn would reduce customer satisfaction due to the increased price for services.

MSUs equipped with phones, web connections, faxes and wireless communications will be used as local MSUs supervision offices which report to the control centre with regard to quality and quantity of services provided and the perceived level of customer satisfaction. Surveys for measuring customer satisfaction, their needs and expectations is suggested to allow smart customisation of MSUs services according to the ethnic groups of pilgrims in each zone.

It can be concluded that the system of MSUs contributes to customers satisfaction through provision of the appropriate amount of quality facilities and services, at reasonable price during the Hajj, wherever and whenever needed.

7.7.8 Implementation of the system of MSUs

The proposed system of MSUs is suggest to be implemented for the Hajj gradually through the following:

1. Spreading the awareness of the characteristics and benefits of the proposed system of MSUs for the Hajj, backed with the findings from this research,
among the service providers, officials and the general public, through presentations, seminars, conferences and publications.

2. Developing and making mobile research units for the Hajj Institute to serve the staff during field work and data collection. This can be used as an example representing the main features of the MSU and as a test bed for further developments.

3. Developing and making selected types of MSUs for some governmental organizations and the private sector and integrating them within the existing Shuttle Buses transportation system. This can be for the establishment of Turkish, European and American pilgrims.

4. Encouraging more private and governmental organizations to develop and make their own MSUs.

5. Expanding the system of MSUs gradually while implementing the master plan for the cities of the Hajj. This is to be supported with research programs for MSUs development.
7.8 The contribution of this research work to knowledge

The review of the literature has revealed that no such system of Mobile Service Units (MSUs), in terms of scope and scale, has been developed for mega events in general and for the Hajj in particular. This research work is novel in developing and investigating such a large scale mobile service system from many perspectives:

The work of Barhamin (1997) indicated that pilgrims want better facilities and services, but are not willing to pay extra money for them, and argued that the only way to achieve this is through effective management of services. This research adds one more way, by making provision of services more profitable, by using MSUs instead of fixed service centres. Higher standards and service quality measures can be applied to commercial service providers, without increasing the cost of their services or relying on subsidies from the government.

The work of many researchers (such as Al Rahman, 1988 and Harigi, 1989) confirms the importance of services for the cities of the Hajj and Al-Medina and highlights their impacts on planning and land use issues. This research work provides a means to provide almost the whole range of services needed, while giving the planners of the cities of the Hajj greater flexibility to relocate MSUs service parking according to the changing land use patterns, rather than being hindered by fixed structures that cost too much to relocate.

The work of Mefford (1993) suggested that quality improvement methods used successfully in manufacturing, such as Just-in-time, can work also in service firms. This research confirms that, and in addition has demonstrated that Just-in-time MSUs, not only improve the quality of services, but also makes them flexible enough to respond to the variable demands at dispersed locations.

The work of Barhamin (1997) concluded that the types of facilities and services required at a particular venue correlate to the programme taking place at that venue. This research has demonstrated that the proposed system of MSUs can provide a flexible way to customize the type of facilities and services to address specific needs.
at each venue, and to address the needs of particular groups of pilgrims at each location.

The web search has revealed that many mobile services are available commercially and are well developed for the international market. This research has demonstrated how a wide variety of diverse mobile services can be integrated, managed successfully and operate efficiently, to form a very-large-scale service system that is capable of serving millions of visitors to Mega-events.

The large fleet of buses that currently form the back-bone of the transportation system for the Hajj, will continue to be the main transportation system for the Hajj in the future as considered by the master plan. They will contribute after the end of their service life in new forms and functions, as Mobile Service Units, as suggested in this research.

This research work has demonstrated an approach to modelling and simulation of a very-large-scale system representing multiple cities, with massive movements of visitors between them. One that possesses a huge shift in demand for services from one place to another, and which needs to be satisfied efficiently.

Most of the literature, in control engineering, has demonstrated how to control systems or plants by changing the values of their inputs in continuous or small discrete steps, while very few examples deal with the case were inputs can only be changed in large discrete values. This research has developed an approach for controlling a large-scale service system of MSUs where different locations/zones compete simultaneously for a limited number of units that have high discrete service capacity, to provide adequate services for their continuously changing number of visitors.

A large number of publications have demonstrated successful application of Fuzzy logic controllers in many engineering and industrial applications, and to some extent in some applications for the service industry. This research adds an exiting application, where fuzzy controllers are used to represent the thinking and the
decision making of service providers, in response to the variable demand for their services, at different locations, within a challenging and competing environment.

The work of Barhamin (1997) concluded that beside the programme quality, the success of a Mega-event depends mainly on the availability, accessibility, affordability, and presentability of facilities and services. This research has demonstrated that the proposed system of MSUs could contribute to the success of the Hajj by making the required services available, accessible and affordable to the expected 4.8 million visitors by year 2025.

The work towards developing and establishing an efficient and cost effective transportation system for the Hajj, the system of Shuttle Buses (described before in Chapter 1), and the development of the new master plan for the cities of the Hajj (Beaeh, 1999), is now complemented, by this research work. This work possesses a large scale mobile service system, capable of providing quality services for the expected number of visitors, and is economically viable to operate commercially, without increasing the cost of services.

This research has used, developed and integrated techniques from various disciplines of Modelling, Simulation, Control engineering, Artificial intelligence, Architecture, Planning, Engineering design, Transportation, Logistics, Service industry and Economics in a multidisciplinary engineering framework in order to develop, investigate and validate the proposed system of MSUs for the Mega event of the Hajj. The findings of this research should contribute, in some degree or another, to the bulk of knowledge in all these disciplines.
CHAPTER EIGHT

Conclusion

The Multi-disciplinary approach used to investigate the proposed system of Mobile Service Units (MSUs) for the Hajj, where millions of pilgrims come to Makkah every year for about two weeks, was found to be very helpful in understanding and developing the system both on a macroscopic and microscopic scales. The analysis of the questionnaire highlighted the requirements and concerns of service providers and these were considered in the proposed system. The various designs of MSUs and their integration with the master plan for the cities of the Hajj demonstrated the ability to construct the proposed system. Modelling and simulation of the system demonstrated that the system is operational and controllable and does not hinder the mass transportation of pilgrims during the Hajj.

It is found that whilst the service providers consider the current services quite sufficient, they are enthusiastic regarding implementation of the proposed Mobile Service Units for the Hajj as 83% of the respondents approved the concept. Service providers contributed actively in determining 44 types of services that they perceived as feasible to be MSUs. This also highlighted the validity of the proposed system from their point of view. Moreover, service providers have considered the 18 different possible hindering factors proposed, more like “concerns” that need to be well addressed and resolved, rather than considering them as “threats” that may prevent establishment of the system. The findings of this research and the master plan have satisfactorily resolved all these concerns.

This research demonstrated how a wide variety of diverse mobile services can be integrated, managed successfully and operate efficiently, to form a very-large-scale service system that is capable of serving millions of visitors to Mega-events. No
such system, in terms of scope and scale, has been developed before for mega events in general and for the Hajj in particular. The possibility of making the proposed system of MSUs has been confirmed from many perspectives. The web search revealed that many mobile services are well developed and available commercially on the international market. This confirms that special MSUs could be designed and built using existing technology. More designs and configurations are proposed to give service providers a wide variety of options for developing their own MSUs. Various urban design layouts have demonstrated how the master plan could be slightly modified to accommodate parking for these MSUs, making them accessible to pedestrians and pilgrim camps. Moreover, an abundant and low-cost resource for making MSUs was identified; hundreds of buses, which are currently used for transportation during the Hajj, go out of service every year. Most types of the proposed MSUs can be made by recycling these out-of-service buses and using them as a resource for low-cost spare parts. Modular extension units are also proposed to simplify converting these buses to spacious MSUs.

This research has developed an approach to modelling and simulation of a very-large-scale system representing multiple cities, with massive movements of visitors between them. One that possesses a huge shift in demand for services from one place to another, and which needs to be satisfied efficiently. Modelling and simulation of the system of MSUs was also found to be a very effective tool in developing the control rules and evaluating their effects, without disturbing the mega-event of the Hajj.

This research developed an approach for controlling such a large-scale service system of MSUs where different locations/zones compete simultaneously for a limited number of units that have high discrete service capacity, to provide adequate services for their continuously changing number of visitors. An approach to ‘Just-In-Time MSUs (JIT-MSUs) has been shown to be feasible in terms of controlling the proposed system of MSUs. Through online control of orders to move MSUs to provide the right services, at the right place, at the right time; achieving higher efficiency and utilization of resources.
Intelligent Fuzzy Logic Controllers were used, on a microscopic scale, to evaluate the situations at every zone and to issue requests for MSUs, and on a macroscopic scale to evaluate these requests according to other conditions relating to the system as a whole. The control centre sorts these evaluated requests and issues orders according to their relative importance and associated control parameters.

Simulation results show that MSUs of Medium service capacity, ranging from 50k to 66.7k inhabitants, are very suitable to be used in the proposed system. They require no additional units and do not significantly affect traffic volume. Lower service-capacity MSUs are also suitable and their performance can be improved, by making use of external spaces, to reduce the number of their units. Very-high-service-capacity MSUs are need to be reduced in capacity and increased in number to increase efficiency. MSUs of Very-low-service-capacity should be used sparingly. Their service capacity should be increased to allow for transportation during peak times.

Simulation results confirm that the proposed system of MSUs will not affect the programmes for transporting pilgrims, since they make use of the unused capacity of the road networks. Simulation results also show that a significant reduction in resources, and a high increase in profit, compared with fixed services is achieved using the proposed MSUs. This should enable service providers to provide higher service quality at a better price.

In conclusion, the goal of this research has been met, the research questions were satisfactory answered and the proposed system of MSUs is expected to contribute to the success of the mega-event of the Hajj by providing an adequate amount of wide-variety, quality facilities and services, at all locations, whenever needed, without increasing the cost of services.
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APPENDIX A

An English translation for the original Arabic questionnaire
A questionnaire for the managers and supervisors responsible of providing services to pilgrims in Makkah and Al-Mashaeer

Dear Sir,

This questionnaire is intended to help developing and providing the different types of services for Pilgrims in Makkah and Al-Mashaeer. It is for the managers and supervisors both in public and private sectors, who are responsible of providing the different types of services for Pilgrims, to benefit from their valuable experience in this field.

Your kind cooperation by answering the questions of this questionnaire precisely is a valuable contribution in a scientific research to develop and provide full and integrated services for the Pilgrims in Makkah and Al-Mashaeer, conducted by a researcher at CTHM Institute for Hajj Research as part of his Ph.D. thesis.

Please read this questionnaire then kindly answer the questions and return it to the secretary of CTHM Institute for Hajj Research.

It should be mentioned that the name and the employer of the respondent were not asked in this questionnaire to ensure unbiased answers. In addition, the answers will be treated confidentially and for research purpose only.

Thank you for your kind cooperation, May God reward you.
1. What is your work sector during Pilgrimage season?
   (Please compare the available answers, then tick inside the square ✓ for one answer only)
   1. Governmental sector.  
   2. Pilgrimage Establishment.  
   3. Tawaf services.  
   4. Private Sector.  
   5. Other. (Please specify) __________________________

2. Is your work in that sector (mentioned in Q1) permanent through the year, or temporary during pilgrimage season?
   (Please compare the available answers, then tick inside the square ✓ for one answer only)
   1. Permanent work through the year.  
   2. Temporary work for pilgrimage season.  
   3. Other (Please specify) __________________________

3. Where is the location of your permanent work other than Pilgrimage season?
   1. Makkah district.  
   2. Another district in Saudi Arabia.  
   3. Outside Saudi Arabia. (Please specify) __________________________

4. Which of the following types best describes your work during pilgrimage season?
   (Please compare the available answers, then tick inside the square ✓ for one answer only)
   1. General supervision  
   2. Field supervision  
   3. Coordinating work  
   4. Field work  
   5. Office work  
   6. Other. (Please specify) __________________________

5. How many times have you joined the work during pilgrimage season (including this year)?
   (Please compare the available answers, then tick inside the square ✓ for one answer only)
   1. Zero.  
   2. Once.  
   3. Twice.  
   4. From (3) to (5) times.  
   5. From (6) to (10) times.  
   6. More than (10) times.  

6. In the following some types of the different services provided for the Pilgrims in Makkah and Al-Maskeer:
   A. Please put the signal ✓ inside the left table after the services provided to pilgrims in Makkah and Al-Maskeer by the department you work with during pilgrimage season?
   B. Then please put the signal ✓ inside the right table after all services (whether provided or not) by the department you work with during pilgrimage season to show your opinion whether you consider it sufficient or not sufficient for pilgrims in Makkah and Al-Maskeer.

| Type of Services | A-Do your department provide this service to pilgrims? | B-Do you think this service is sufficient for pilgrims in Makkah and Al-Maskeer? |
|------------------|--------------------------------|---------------------------------|---------------------------------|
|                  | Yes | No | Currently Sufficient | Sufficient | Not Currently Sufficient | Not Sufficient | I Don't Know |
| Example: (Reservation by Phone) | ✓ | | | | |
| 1. Emergency services | | | | | |
| 2. Medical care services | | | | | |
| 3. Food and drink services | | | | | |
| 4. Security services | | | | | |
| 5. Safety and fire fighting services | | | | | |
| 6. Administrative and management services | | | | | |
| 7. Telephone services | | | | | |
| 8. Post, Fax, and Telex services | | | | | |
| 9. Transportation services | | | | | |
| 10. Accommodation services | | | | | |
| 11. Educational and awareness services | | | | | |
| 12. Public relations services | | | | | |
| 13. VIP hospitality services | | | | | |
| 14. Lost people guidance services | | | | | |
| 15. Social or recreational services | | | | | |
### 7. What is the maximum estimated number of pilgrims using all the services provided by your department in Makkah and Mashaer every day?

*Please compare the available answers, then tick inside the square √ for one answer only*

1. Less than (100) pilgrims. □
2. From (101) to (500) pilgrims. □
3. From (501) to (1000) pilgrims. □
4. From (1001) to (3000) pilgrims. □
5. More than (3000) pilgrims. □
6. Another number □ (Please specify) ________

### 8. A brief description of the proposed solution for developing and providing integrated services for pilgrims in Makkah and Al-Mashaer:

Providing fixed integrated services covering all the needs of pilgrims in Arafat, Muzdalifah, and Mina (known as Al-Mashaer) in addition to Makkah, are probably difficult to achieve practically. Since to provide services for (3 million pilgrims) for example necessitates repeating these fixed services in every place, which makes the total service capacity enough to serve (12 million pilgrims), while serving only (3 million pilgrims) at the same time. Due to the short stay of pilgrims in each place, and the high cost of construction and provision, the economical feasibility to provide these services becomes low, which may limit the contribution of private sector, and increases the load to the governmental sector.

The researcher suggests for solving this problem, the concept of adaptation of trucks and trailers to function as Transportable Service Centres "MSU", for the different services provided for pilgrims (e.g.: clinics, heat stoke treatment, medical care, induction, lost people guidance, information, communication, fire fighting, police, administration site office, commercial services, pay toilets, garbage press, etc.). Service parking for these MSU will be located near pilgrims camps, and can be accessible through pedestrian walkways, which spread these services in all pilgrim places. Service parking will be supplied by infrastructure utilities (water, sewage, electricity, and communication) and connected to MSU by flexible cables and pipes. The movement of these MSU will be scheduled before and after the movement of the Pilgrims, using road networks to be assigned in the future for the shuttle buses system.

These MSU can be manufactured in local factories making trucks and trailers, and can be made by reconditioning old out-of-service buses to function as MSU. The economical feasibility is expected to be achieved by using these MSU in all pilgrims areas during pilgrimage season, and in other places after Hajj season such as rural and tourism areas, in addition to use it as a national emergency facilities.
9. What is your opinion in putting the following services in movable trucks or trailers to serve pilgrims in Makkah and Al-Mashaer?
(Please mark ✓ inside the table after the name of each service)

<table>
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<tr>
<th>Type of services</th>
<th>Feasible very much</th>
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<th>Not feasible</th>
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<td>Example (instant printing centre)</td>
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<td>Healthy services</td>
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<td>3. Heat stroke treatment</td>
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<td>Security services</td>
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<td>4. Security and police centre</td>
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<td>5. Safety and fire fighting centre</td>
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<td>6. Civilian security guard centre</td>
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<td>7. Traffic management centre</td>
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<td>8. TV camera surveillance centre</td>
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<td>Educational and awareness centre</td>
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<td>9. Lost people guidance centre</td>
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<td>10. Information centre</td>
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<td>11. Centre for governmental publicity</td>
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<td>12. Exhibition for the history of holy places</td>
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<td>13. Telephone cabins and communications centre</td>
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<td>14. Post office and fax service centre</td>
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<td>15. Internet services centre</td>
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<td>16. Translation services centre</td>
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<td>18. Lost properties service centre</td>
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<td>19. Nursery</td>
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<td>20. Elderly and disabled people care centre</td>
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<td>21. Pilgrims public relations centre</td>
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<td>22. Sitting hall for pilgrims</td>
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<td>23. VIP hospitality hall</td>
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<td>24. Social or recreational centre</td>
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<td>25. TV and radio hall</td>
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<td>Social and support services</td>
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<td>26. Cafeteria or restaurant</td>
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<td>27. Dining hall</td>
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<td>28. Food selling or distributing lorry</td>
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<td>29. Water &amp; drinks selling or distributing lorry</td>
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<td>30. Central kitchen for camps</td>
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<td>31. Fast food wholesale factory</td>
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<td>32. Automatic bakery</td>
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<td>33. Ice cube machines</td>
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<td>34. Purifying and cooling water unit</td>
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<td>Public services and utilities</td>
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<td>35. Luggage keeping and safe deposit centre</td>
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<td>36. Barber shop</td>
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<td>37. Laundry service centre</td>
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<td>38. Public toilets</td>
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<td>39. Commercial pay toilets</td>
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<td>40. Tickets selling centre</td>
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<td>41. Bank branch</td>
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<td>42. Currency exchange office</td>
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<td>43. General shops</td>
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<td>46. Central administrative office</td>
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<td>47. Field supervision office</td>
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<td>48. Transportation management office</td>
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<td>49. Meeting room</td>
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<td>50. Supervisors accommodation</td>
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<td>51. Field survey data collection office</td>
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<td>52. Movable field laboratory</td>
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<td>53. Weather station</td>
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<td>54. Environmental &amp; hygiene control office</td>
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<td>55. Cleaning equipment and labour centre</td>
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<td>56. Garbage compressing unit</td>
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<td>57. Public facilities maintenance centre</td>
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<td>58. Bus and vehicle workshop</td>
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<td>59. Floodlight tower movable unit</td>
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10. Do you suggest another services and facilities suitable to be movable? Please specify:

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11. To what extent the following factors may hindering or not hindering the implementation of transportable services centres in Makkah and Al-Mashaer?

(Please compare the available answers, then put the signal ✓ inside the square that represent your opinion after each factor)

<table>
<thead>
<tr>
<th>Hindering factors (Relates to the existing conditions)</th>
<th>Not-Hindering at all</th>
<th>Relatively not hindering</th>
<th>Hindering Slightly</th>
<th>Extremely Hindering</th>
<th>I don't know</th>
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<tbody>
<tr>
<td>1. Existing road network</td>
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<td>2. Crowded pedestrian walkways</td>
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<td>3. Traffic jams on car roads</td>
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<td>4. Existing available services</td>
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<td>5. The existing way in providing services</td>
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<td>6. The existing administrative rolls</td>
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<td>7. The existing available infrastructures</td>
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<tr>
<th>Hindering factors (Relates to the concept of transportable services centres)</th>
<th>Not-Hindering at all</th>
<th>Relatively not hindering</th>
<th>Hindering Slightly</th>
<th>Extremely Hindering</th>
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<tr>
<td>8. The way pilgrims will use them</td>
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<td>9. The space available to park them</td>
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<td>10. The cost to manufacture them</td>
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<td>11. Their manufacturing process</td>
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<td>12. The network of exclusive bus roads</td>
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<td>13. The time available to transport them</td>
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<td>14. The time available to prepare them</td>
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<td>15. The availability of manpower to operate them</td>
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<td>16. Their operation process</td>
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<td>17. Their maintenance process</td>
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<td>18. Their storage process</td>
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12. Are there any other factors not mentioned in the previous question that may hinder the implementation of Transposable Services Centres in Makkah and Al-Masaeer? Please specify:

________________________________________________________________________
________________________________________________________________________
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________________________________________________________________________

13. In general what is your opinion in putting most pilgrim's services in lorries and trailers that transported from one place to another before and after the movement of pilgrims through the roads assigned for shuttle buses? (Please compare the available answers, then tick inside the square ✓ after one answer only)

1. Strongly agree ☐
2. Agree ☐
3. Slightly agree ☐
4. Slightly disagree ☐
5. Disagree ☐
6. Strongly disagree ☐
7. I don't know ☐

14. Do you have any suggestions or opinions relating to this subject, please specify:

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

15. Please use additional papers if you have more suggestions, and include any reports or publications you feel their importance to the study.

Thank you very much, May GOD rewards you

Please return this questionnaire (preferable before the end of Hajj month) to the secretary of CTHM Institute for Hajj Research, Umm Al-Qura University, P.O.Box 715 Makkah Saudi Arabia, Phone: 02 5572932, Fax: 02 5573282
APPENDIX B

Additional Figures
Figure B1: Response of the control due to the best settings for MSU-group-1

Figure B2: Response of the control due to the worst settings for MSU-group-1
Figure B3: Response of the control due to the best settings for MSU-group-2.

Figure B4: Response of the control due to the worst settings for MSU-group-2.
Figure B5: Response of the control due to the best settings for MSU-group-3

Figure B6: Response of the control due to the worst settings for MSU-group-3
Figure B11: Response of the control due to the best settings for MSU-group-6

Figure B12: Response of the control due to the worst settings for MSU-group-6
Figure B19: Response of the control due to the best settings for MSU-group-10

Figure B20: Response of the control due to the worst settings for MSU-group-10
Figure B21: Response of the control due to the best settings for MSU-group-11

Figure B22: Response of the control due to the worst settings for MSU-group-11
Figure B23: Response of the control due to the best settings for MSU-group-12

Figure B24: Response of the control due to the worst settings for MSU-group-12
Figure B27: Response of the control due to the best settings for MSU-group-14

Figure B28: Response of the control due to the worst settings for MSU-group-14
Figure B29: Response of the control due to the best settings for MSU-group-15

Figure B30: Response of the control due to the worst settings for MSU-group-15
Figure B31: Response of the control due to the best settings for MSU-group-16

Figure B32: Response of the control due to the worst settings for MSU-group-16
APPENDIX C

Additional Tables
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<th>Service Group</th>
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Table C2: Statistics and evaluation of simulation results for selected MSUs-groups at their worst stable control settings

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APPENDIX D

Special Matlab Functions
function `RlveFutServStat`

This function 'RlveFutServStat' is used in the final model to calculate the expected service status after a specified time 'FutureTimeSpan' relative to service capacity of MSU.

```plaintext
function FutureStatus = RlveFutServStat(input);

global PopVsTimeAll; % data file for the population/demand for the four areas
global FutureTimeSpan; % time span to look ahead, 1 hr = 40 simulation steps

CurrentSupply = input(1);
MsuCapacity = input(2);
ZoneGroup = input(3); % 2: Makkah, 3: Mina, 4: Arafat, 5: Muzdalifa
SimulationStep = input(4)+1;

FutureStatus = 0;
FutureTime = 1;

FutureTime = SimulationStep + FutureTimeSpan;

if FutureTime > 6700 % to limit the end of search to the end of data file
    FutureTime = 6723 - SimulationStep;
end

FutureStatus = (CurrentSupply - PopVsTimeAll(FutureTime,ZoneGroup)) / MsuCapacity;
```

function `MsuOrders2`

This function 'MsuOrders2' is used to sort re-evaluated MSUs-requests then issues orders to returning and sending MSUs according to some considerations.

```plaintext
function Orders = MsuOrders2(input)
% this function returns un-needed MSUs, sends highly needed MSUs and sends and releases MSUs according to their need

FuzzyMSUs = input(1:16);
AvailableMSUs = input(17);
DirectAcceptScore = input(18); % InstantAcceptScore
global MinAcceptScoreG; % instead of input(19);
global MaxReturnScoreG; % instead of input(20);
DirectReturnScore = input(21); % InstantReturnScore
TrafficVolume = input(22);
BatchSize = input(23);
ServGroup = input(24);

global PrevisOrders; % (16,16) matrix (j) for MSUs sent to zones, or (-1) for MSUs returned from zones, zones in rows and services in columns

Orders = zeros(16,2); % column_1 for orders to return MSUs, column_2 for orders to send MSUs

MinAcceptScore = MinAcceptScoreG;
MaxReturnScore = MaxReturnScoreG;

MsuToReturn = 0;
MsuToReturn2 = 0;
MsuToSend = 0;
ExpectTraffic = 0;

ExpectTraffic = TrafficVolume;

% ------ Return all MSUs that are not needed any more and make them available for other zones ------
for j=1:16
    if FuzzyMSUs(j) <= DirectReturnScore
        Orders(j,1) = 1; % the order to return an MSU from zone (j)
        AvailableMSUs = AvailableMSUs + 1; % the MSU returned to Support Zone
        FuzzyMSUs(j) = 0; % the same MSU will not be selected again
    end
end

% ------ end of (j)\% returning un-needed MSUs ------

% ------ Send MSUs to all zones that badly need them even by returning other MSUs ------
for k=1:16
    if Case 1: If there is no MSU at support zone and MSUs are badly needed, then return least needed MSUs up to 0
```
if FuzzyMSU(k) => DirectAcceptScore & AvailableMSUs < 1
for k = 1:16, % these are the lowest rated MSUs that should be returned
if FuzzyMSU(k) < 0 & MaxToReturn < 0; % select the first MSU that below zero at
beginning
    MaxToReturn = k;
end
end % end of (k); search for least needed MSUs to be returned
if FuzzyMSU(n) < 0 & MaxToReturn < 0 & FuzzyMSU(k) <
FuzzyMSU(MaxToReturn) % least needed MSUs found
    MaxToReturn = k;
end
end % end of (k); search for least needed MSUs to be returned
if FuzzyMSU(n) < 0 & MaxToReturn < 0 & FuzzyMSU(k) <
Orders(MMaxToReturn, 1) = 1; % the order to return an MSU from the selected zone
AvailableMSUs = AvailableMSUs + 1; % the MSU returned to Support Zone
FuzzyMSU(MaxToReturn) = 0; % the same MSU will not be selected again
MaxToReturn = 0; % to start search again from beginning
end
% end % end of Case 1 by making 1 MSU (score <0) available so that Case 2 will be valid

% Case 2: If MSU is available at support zone, then send MSUs to badly needed zones
if FuzzyMSU(n) = DirectAcceptScore & AvailableMSUs > 1 % there is at least 1 MSU
Orders(k,2) = 1; % the order to send an MSU to zone (k)
AvailableMSUs = AvailableMSUs + 1; % the MSU sent out from Support Zone
FuzzyMSU(k) = 0; % the same MSU will not be selected again
ExpectTraffic = ExpectTraffic + BatchSize;
end % end of Case 2

% if ExpectTraffic => 75, break; end; % stop if total traffic & MSUs to be send => 750 LV/hr
% 4 Lanes
end % end of (k); sending MSUs to all zones that badly need them

% ========= Send MSUs to highest needy zones and return least needed MSUs if necessary
% provided that it is not contradicting previous orders recorded on "PrvisReturnOrds" & "PrievSendOrds" and for the same service ===========
for m = 1:16
    ExpectTraffic = ExpectTraffic + BatchSize;
    if ExpectTraffic <= 75; break; end; % stop if traffic volume will exceed 750 LV/hr
end % end of (m); sending and returning MSUs

if MaxToSend > 0 & AvailableMSUs < 1
for m = 1:16 % select the least needy zone
if FuzzyMSU(n) <= MaxReturnScore & MaxToReturn = 0
    MaxToReturn = n;
end
if FuzzyMSU(n) <= MaxReturnScore & MaxToReturn = 0 &
FuzzyMSU(n) = FuzzyMSU(MaxToReturn)
    MaxToReturn = n;
end
end % end of (n); by knowing which zone can return an MSU
if FuzzyMSU(n) <= MaxReturnScore & FuzzyMSU(MaxToReturn) = 0
    % 1 % MSU is found and selected to be returned and not send in the previous order
    Orders(MMaxToReturn, 2) = 1; % the order to return an MSU from the selected zone
    AvailableMSUs = AvailableMSUs + 1; % the MSU returned to Support Zone
    FuzzyMSU(MaxToReturn) = 0; % the same MSU will not be selected again
    MaxToReturn = 0; % to start search again from beginning
end
end % end of Case 3 by making 1 MSU available if possible so Case 4 will be valid

% Case 4: MSU is available at support zone and needed somewhere
if FuzzyMSU(n) <= MaxReturnScore & AvailableMSUs = 1 % & min (Orders(MMaxToSend, 1) = 1 % send an MSU to the zone if not returned in previous order
    Orders(MMaxToSend, 2) = 1; % the order to send one MSU batch to zone (j)
    AvailableMSUs = AvailableMSUs - 1; % the MSU sent out from Support Zone
    FuzzyMSU(MaxToSend) = 0; % the same MSU will not be selected again
end % end of Case 4
end % end of (m); sending and returning MSUs

%
function RunModel3

The function used to repeatedly run simulation and change settings

function RunModel3

% pause (20);

RunNom = 1;
global ExtraMSU;
global MinAcceptScoreG;
global MaxReturnScoreG;

for a = 0:0.6;
    ExtraMSU = [1.6 1.6 1.2 1.2 1.2 1.2 1.2 1.2 1.2 1.2 1.4 1.4 1.2 1.2] + e;
end

for d = 1:2 % FutureTimeSpan from 1 hr to 6 hr (6 times)
    FutureTimeSpan = fix(20*d);
end

for a = 3:0.2:4 % MinAcceptScore from 3 to 5 with 0.2 increment (10 times)
    MinAcceptScoreG = a;
end

for r = 0.2:0.4 % MaxReturnScore from -0.2 to -5 with -0.2 increment (abs of MaxReturn >= MinAccept)
    MaxReturnScoreG = r;
    pause(10);
end

sim('sims_modeller_1_loop')

pause(10);

% load all files to workspace
load Pop111; load Serv111; load Status111; load Rqst111;
load Pop211; load Serv211; load Status211; load Rqst211;
load Pop411; load Serv411; load Status411; load Rqst411;
load Pop311; load Serv311; load Status311; load Rqst311;
load FuOrd;
load MaxOrd;
load MaxAvbc;
load AvlbMaxArStore;
load TotaMaxUsed;
load MSUsTrfcVolume;
load TrafficVolume;

% pause (50);

for j = 1:16 % services 1,2,3,16 files
    for i = 1:4 % zones 111,211,311 and 411 files

ZonServs{1};
% load files
ZonNum = num2str(j);
SrvNum = num2str(i);
FData3=[ZonNum '111' SrvNum];
z2 = [load 'FData3';
    % eval(z2);
    % eval(FData3);
end % end of i

End % end of j

pause(20);

ExtraMSU
FutureTimeSpan
MinAcceptScoreG
MaxReturnScoreG

RunNom = RunNom + 1;
RunNom2 = num2str(RunNom);
randdata=[RunNo_4_RunNom2];
mm = ['save ' randdata']
eval(mm);

pause(10);

end % end of r
end % end of a
end % end of d
end % end of e
function OrdersFluctConts1

The function used for counting MSUs' unstable orders

function OrdersFluctConts1

OrdCountMat = zeros(19,17,169); % row 1:16 for zones 1:16, column 1:16 for services 1:16, row 17 totals for each service, column 17 totals for each zone, (17,17) for totals for all, row 18 for run settings and 3rd dimension for each run

% load MsoOrd

for rr = 2:169 % for each run

RunNom = num2str(rr);
rundata = [RunNo_4., RunNom];
rr = [rr', rundata];
eval(rr);

for r = 1:6561 % (6721 - 160) to avoid exceeding the end of file

Serv = MsoOrd(18,1); % the number of service group is in row 18

for m = 1:16 % for all 16 zones, zone 1 in row 2, zone 16 in row 17 of MsoOrd
    FirstOrder = MsoOrd(m+1,1);
    NextOrder = MsoOrd(m+1,1+160); % the function MsoOrders2 prevent conflicting orders for last 10 orders

    Ord = FirstOrder + NextOrder;
    if Ord == 0 & FirstOrder == 0 & NextOrder == 0 % search for change from (1 to -1) or (-1 to 1) that reflects unstability of MSU orders
        OrdCountMat(m, Serv, rr) = OrdCountMat(m, Serv, rr) + 1; % total unstable orders for each zone for each service
    end
end % m end of calculation for all zones

end % r (rr) end of calculation for all services

% record the settings of the run in row 18

OrdCountMat (19, 1:16, rr) = ExtraMSU;
OrdCountMat (18, 1, rr) = 1; % run number
OrdCountMat (18, 2, rr) = FutureRadioButton;
OrdCountMat (18, 3, rr) = MinAccepScoreG;
OrdCountMat (18, 4, rr) = MaxReturnScoreG;

end % (rr) for all run files

% OrdCountMat

save OrdCountMatFile OrdCountMat % save the matrix in a file

function StatusStatisticsAll2

The function used to calculate statistics for each run

function StatusStatisticsAll2

StatMatrix = zeros(13,13,169);

for rr = 2:169 % for each run

RunNom = num2str(rr);
rundata = [RunNo_4., RunNom];
rr = [rr', rundata];
eval(rr);

load OrdCountMatFile; % load the file that contains the counts of unstable orders
TotalMsoUsed = TotalMsoUsed + % rearrange the file from (17x6721) to (6721x17) for Max number of MSUs used service 1 in column 2
ExtraMSU = ExtraMSU +;

MsoStatData = []; MinStatData = []; ArfStatData = []; MzStatData = []; AllStatData = [];

DataServ1 = []; DataServ2 = []; DataServ3 = []; DataServ4 = [];

% variables for Makkah
MaximumStatus1 = 0; MinimumStatus1 = 0; MaxServ1 = 0; MinServ1 = 0; NoRow1 = 0;

% variables for Mina
MaximumStatus2 = 0; MinimumStatus2 = 0; MaxServ2 = 0; MinServ2 = 0; NoRow2 = 0;

% variables for Maldafhi
MaximumStatus3 = 0; MinimumStatus3 = 0; MaxServ3 = 0; MinServ3 = 0; NoRow3 = 0;

% variables for Arafat
MaximumStatus4 = 0;
% variables for all zones
MaximumStatus=0;
MinimumStatus=0;
MaxServ=0;
MaxZone={};
MinServ=0;
MinZone={};
NoRows=0;

for j=1:16 % services 1,2,3...16 files
MaxStatus=0;
MaximumStatus=0;
MinimumStatus=0;
MaxZone={};
MinZone={};
NoRows=0;
StatData[]={};

for i=1:4 % zones 111, 211, 311 and 411 files

% load files
ZonNum= num2str(i);
SrvNum= num2str(j);
ifData3=['Z ZonNum 'SrvNum SrvNum];
% read data
Data = eval(ifData3);

Data=Data;
MinStatus = min(Data(:,2));
MaxStatus = max(Data(:,2));

% Min and Max for service j
if MinStatus < MinimumStatus % Record the Maximum Over supply and the zone no
MinimumStatus = MinStatus;
MinZone = [ZonNum '11'];
end
if MaxStatus > MaximumStatus % Record the Maximum Over supply and the zone no
MaximumStatus = MaxStatus;
MaxZone = [ZonNum '11'];
end
% Total under and over supplies

StatData={[StatData; Data(:,2)]}; % put all four files for the four zone in one matrix

if i==1, % All services status at Makkah
MakkStatData={[MakkStatData; Data(:,2)]}; % Find the Max and Min for Makkah for what service
if MaxStatus < MinimumStatus1 % Record the Maximum Over supply and the service no
MinimumStatus1 = MinStatus;
MaxServ1 = j;
end
if MaxStatus > MaximumStatus1 % Record the Maximum Over supply and the service no
MaximumStatus1 = MaxStatus;
MaxServ1 = j;
end
end

if i==2, % All services status at Mina
MinaStatData={[MinaStatData; Data(:,2)]}; % Find the Max and Min for what service
if MinStatus < MinimumStatus2 % Record the Maximum Over supply and the service no
MinimumStatus2 = MinStatus;
MinServ2 = j;
end
if MaxStatus > MaximumStatus2 % Record the Maximum Over supply and the service no
MaximumStatus2 = MaxStatus;
MinServ2 = j;
end
end

if i==3, % All services status at Arafat
ArafStatData={[ArafStatData; Data(:,2)]}; % Find the Max and Min for what service
if MinStatus < MinimumStatus3 % Record the Maximum Over supply and the service no
MinimumStatus3 = MinStatus;
MinServ3 = j;
end
if MaxStatus > MaximumStatus3 % Record the Maximum Over supply and the service no
MaximumStatus3 = MaxStatus;

if i==4, % All services status at Muzdalifah
MuzdStatData={[MuzdStatData; Data(:,2)]}; % Find the Max and Min for what service
if MinStatus < MinimumStatus3 % Record the Maximum Over supply and the service no
MinimumStatus3 = MinStatus;
MinServ3 = j;
end
if MaxStatus > MaximumStatus3 % Record the Maximum Over supply and the service no
MaximumStatus3 = MaxStatus;
end

D - 9

D - 10
MaxServ3 = j;
end

% all services at all zones
AllStatData = [AllStatData; Data(:,2)];
if MinStatus < MinimumStatus5 % Record the Maximum Over supply, service no and zone
MinimumStatus5 = MinStatus;
MaxServ5 = j;
MinZone5 = [MinNum '11'];
end
if MaxStatus > MaximumStatus5 % Record the Maximum Over supply, service no and zone
MaximumStatus5 = MaxStatus;
MaxServ5 = j;
MinZone5 = [MinNum '11'];
end

end % end of i

% Record service status for selected services to be used in drawing Histograms
if j=2; DataServ2=StatData; end % record status for service 2 at all zones
if j=5; DataServ5=StatData; end % record status for service 5 at all zones
if j=7; DataServ7=StatData; end % record status for service 7 at all zones
if j=8; DataServ8=StatData; end % record status for service 8 at all zones

% Statistics for one service at all zones
[r,c] = size(StatData);
NoRows=r;
for sa=1: % calculate total under and over supplies
if StatData(saa,1) < 0 % under supply detected
StatMatrix(j,7, rr)=StatMatrix(j,7, rr) + StatData(saa,1); % add the under supply to Total
Under Supply cell at column no 7
if j=1; % All services status at Makkah
StatMatrix(17,7, rr)=StatMatrix(17,7, rr) + StatData(saa,1); % sum total under supplies for all services in Makkah
end
if j=2; % All services status at Mina
StatMatrix(18,7, rr)=StatMatrix(18,7, rr) + StatData(saa,1); % sum total under supplies for all services in Mina
end
if j=4; % All services status at Arafat
StatMatrix(20,7, rr)=StatMatrix(20,7, rr) + StatData(saa,1); % sum total under supplies for all services in Mina
end
end
% sum total over supplies
if j=1; % All services status at Makkah
StatMatrix(17,10, rr)+StatMatrix(17,10, rr) + StatData(saa,1); % add the over supply to Total
Over Supply cell at column no 7
if j=2; % All services status at Mina
StatMatrix(18,10, rr)=StatMatrix(18,10, rr) + StatData(saa,1); % sum total over supplies for all services in Mina
end
if j=4; % All services status at Arafat
StatMatrix(20,10, rr)=StatMatrix(20,10, rr) + StatData(saa,1); % sum total over supplies for all services in Arafat
end
end
% percentage of total over under supplies
if j=1; % All services status at Makkah
StatMatrix(21,10, rr)=StatMatrix(21,10, rr) + StatData(saa,1); % percentage of total over under supplies
end
if j=2; % All services status at Mina
StatMatrix(21,10, rr)=StatMatrix(21,10, rr) + StatData(saa,1); % percentage of total over under supplies
end
if j=4; % All services status at Arafat
StatMatrix(21,10, rr)=StatMatrix(21,10, rr) + StatData(saa,1); % percentage of total over under supplies
end

% Statistics for one service at all zones
[r,c] = size(MakkahStatData);
NoRows=r;
for sa=1: % calculate total under and over supplies
if MakkahStatData(saa,1) < 0 % under supply detected
MakkahStatMatrix(j,7, rr)=MakkahStatMatrix(j,7, rr) + MakkahStatData(saa,1); % add the under supply to Total
Under Supply cell at column no 7
if j=1; % All services status at Makkah
MakkahStatMatrix(17,7, rr)=MakkahStatMatrix(17,7, rr) + MakkahStatData(saa,1); % sum total under supplies for all services in Makkah
end
if j=2; % All services status at Mina
MakkahStatMatrix(18,7, rr)=MakkahStatMatrix(18,7, rr) + MakkahStatData(saa,1); % sum total under supplies for all services in Mina
end
if j=4; % All services status at Arafat
MakkahStatMatrix(20,7, rr)=MakkahStatMatrix(20,7, rr) + MakkahStatData(saa,1); % sum total under supplies for all services in Mina
end
% sum total over supplies
if j=1; % All services status at Makkah
MakkahStatMatrix(17,10, rr)+MakkahStatMatrix(17,10, rr) + MakkahStatData(saa,1); % add the over supply to Total
Over Supply cell at column no 7
if j=2; % All services status at Mina
MakkahStatMatrix(18,10, rr)=MakkahStatMatrix(18,10, rr) + MakkahStatData(saa,1); % sum total over supplies for all services in Mina
end
if j=4; % All services status at Arafat
MakkahStatMatrix(20,10, rr)=MakkahStatMatrix(20,10, rr) + MakkahStatData(saa,1); % sum total over supplies for all services in Arafat
end
end
% percentage of total over under supplies
if j=1; % All services status at Makkah
MakkahStatMatrix(21,10, rr)=MakkahStatMatrix(21,10, rr) + MakkahStatData(saa,1); % percentage of total over under supplies
end
if j=2; % All services status at Mina
MakkahStatMatrix(21,10, rr)=MakkahStatMatrix(21,10, rr) + MakkahStatData(saa,1); % percentage of total over under supplies
end
if j=4; % All services status at Arafat
MakkahStatMatrix(21,10, rr)=MakkahStatMatrix(21,10, rr) + MakkahStatData(saa,1); % percentage of total over under supplies
end

% overall statistics for all services at Makkah (row no 17)
[r,c] = size(MakkahStatData);
NoRows=r;
MakkahStatMatrix(17,10, rr)=sum(webCountMat(:,1, 17, rr)); % sum data from OrdCountMat for unsatable orders for Makkah
MakkahStatMatrix(17,10, rr)=mean(MakkahStatData); % Mean of Status
MakkahStatMatrix(17,10, rr)=std(MakkahStatData); % Standard Deviation of Status
MakkahStatMatrix(17,10, rr)=MinimumStatus; % Minimum under supply
MakkahStatMatrix(17,10, rr)=MinimumStatus; % Minimum under supply
MakkahStatMatrix(17,10, rr)=MinServ; % zone of minimum under supply
% StatMatrix[17, 7, mr] for total under supplies for all services in Makkah is recorded in previous loop
StatMatrix[17, 7, mr] = MaximumStatus1; % Maximum Over supply
StatMatrix[17, 9, mr] = MaxServ1; % zone of Maximum over supply
StatMatrix[17, 10, mr] for total over supplies is recorded in previous loop

% Statistics for all services at Mina (row no 18)
[12, 2] = size(MinaStatData); NoRows2=2;
StatMatrix[18, 1, mr] = sum (OrdCountMat [8. 17, mr]) ; % copy data from OrdCountMat for unstable orders for Mina
StatMatrix[18, 2, mr] = NoRows2; % Total number of fluctuations for Makkah = no. of rows
StatMatrix[18, 3, mr] = mean(MinaStatData), % Mean of Status
StatMatrix[18, 4, mr] = std(MinaStatData); % Standard Deviation of Status
StatMatrix[18, 5, mr] = MinimumStatus2; % Minimum under supply
StatMatrix[18, 6, mr] = MaxServ2; % zone of minimum under supply
StatMatrix[18, 7, mr] for total under supplies for all services in Mina is recorded in previous loop
StatMatrix[18, 8, mr] = MaximumStatus2; % Maximum Over supply
StatMatrix[18, 9, mr] = MaxServ2; % zone of Maximum over supply
StatMatrix[18, 10, mr] for total over supplies is recorded in previous loop

% Statistics for all services at Arafat (row no 19)
[4, 4] = size(ArafStatData); NoRows4=4;
StatMatrix[19, 1, mr] = sum (OrdCountMat [12.16, 17, mr]) ; % copy data from OrdCountMat for unstable orders for Arafat
StatMatrix[19, 2, mr] = NoRows4; % Total number of fluctuations for Makkah = no. of rows
StatMatrix[19, 3, mr] = mean(ArafStatData); % Mean of Status
StatMatrix[19, 4, mr] = std(ArafStatData); % Standard Deviation of Status
StatMatrix[19, 5, mr] = MinimumStatus4; % Minimum under supply
StatMatrix[19, 6, mr] = MaxServ4; % zone of minimum under supply
StatMatrix[19, 7, mr] for total under supplies for all services in Arafat is recorded in previous loop
StatMatrix[19, 8, mr] = MaximumStatus4; % Maximum Over supply
StatMatrix[19, 9, mr] = MaxServ4; % zone of Maximum over supply
StatMatrix[19, 10, mr] for total over supplies is recorded in previous loop

% Statistics for all services at Mudafalah (row no 20)
[3, 3] = size(MudStatData); NoRows3=3;
StatMatrix[20, 1, mr] = sum (OrdCountMat [8.12, 17, mr]) ; % copy data from OrdCountMat for unstable orders for Mudafalah
StatMatrix[20, 2, mr] = NoRows3; % Total number of fluctuations for Makkah = no. of rows
StatMatrix[20, 3, mr] = mean(MudStatData); % Mean of Status
StatMatrix[20, 4, mr] = std(MudStatData); % Standard Deviation of Status
StatMatrix[20, 5, mr] = MinimumStatus3; % Minimum under supply
StatMatrix[20, 6, mr] = MaxServ3; % zone of minimum under supply
StatMatrix[20, 7, mr] for total under supplies for all services in Mudafalah is recorded in previous loop
StatMatrix[20, 8, mr] = MaximumStatus3; % Maximum Over supply
StatMatrix[20, 9, mr] = MaxServ3; % zone of Maximum over supply
StatMatrix[20, 10, mr] for total over supplies is recorded in previous loop

% Statistics for all services at all zones (rows no 21 & 22)

end end of rrr
format short;
save Statistics2 StatMatrix;
function FuzzyEvaluateRuns
The function and Fuzzy logic used to score runs

function FuzzyEvaluateRuns
load Statistics2;
% StatMatrix is (23,13, 169) = (services, statistics, runs), services 1:16 in rows 1:16,

for ss=1:16 % check for service (ss)
ServStatSS=[];
for rrr=2:169 % for all runs, collect stable runs, run no 1 is not available
if StatMatrix(ss, 1, rrr) == 0 % no unstable orders detected
ServStatSS=[ServStatSS; StatMatrix(ss, rrr)]; % extract the row and add it to matrix ServStatSS
end
end % end (rrr)
ServStatSS = abs(ServStatSS); % take absolute value to evaluate both positive and negative values
MaxValues = max(ServStatSS); % maximum values
MinValues = min(ServStatSS); % minimum values
DataRange= (MaxValues - MinValues) + 0.00000001; % DataRange (1, 13) = 0.0001 to avoid division by zero

for r2=2:169 % for all runs, run no 1 is not available
if StatMatrix(ss, 1, r2) == 0 % unstable orders detected
StatMatrix(ss,13, r2) = 0; % This run for service (ss) is failed due to unstable orders
end
if StatMatrix(ss, 1, r2) == 0 % no unstable orders occurred, therefore evaluate this run for service ss
MeanVal = (ssb(StatMatrix(ss, 3, r2))) - MinValues (1, 3) / DataRange (1, 3); % Relative Mean value in range [0 1]
StdVal = (ssb(StatMatrix(ss, 4, r2))) - MinValues (1, 4) / DataRange (1, 4); % Relative Standard Deviation value in range [0 1]
MinSuppVal = (ssb(StatMatrix(ss, 5, r2))) - MinValues (1, 5) / DataRange (1, 5); % Relative Minimum Under Supply value in range [0 1]
TotUnSuppVal = (ssb(StatMatrix(ss, 7, r2))) - MinValues (1, 7) / DataRange (1, 7); % Relative Total Under Supply value in range [0 1]
TotOvSuppVal = (ssb(StatMatrix(ss, 10, r2))) - MinValues (1, 10) / DataRange (1, 10); % Relative Mean value in range [0 1]
MaxMauUsed= (ssb(StatMatrix(ss, 11, r2))) - MinValues (1, 11) / DataRange (1, 11); % Relative Standard Deviation value in range [0 1]

fismat1 = readfis('FuzzyEvaluation1');
Score1 = evalfis(MeanVal,fismat1);

fismat2 = readfis('FuzzyEvaluation2');
Score2 = evalfis(StdVal,fismat2);

fismat3 = readfis('FuzzyEvaluation3');
Score3 = evalfis(MinSuppVal,fismat3);

fismat4 = readfis('FuzzyEvaluation4');
Score4 = evalfis(TotUnSuppVal,fismat4);

fismat5 = readfis('FuzzyEvaluation5');
Score5 = evalfis(TotOvSuppVal,fismat5);

fismat6 = readfis('FuzzyEvaluation6');
Score6 = evalfis(MaxMauUsed,fismat6);

StatMatrix(ss,12, r2) = (Score1 + Score2 + Score3 + Score4 + Score5 + Score6) / 6; % total score is the average of all scores
end
end % of (r2) for all runs
end % of (ss) for all services
save Statistics22 StatMatrix;
function BestBadSettings

The function used to identify best and worst settings

function BestBadSettings

load Statistics12 % StatMatrix;
EvaluationResults= zeros (16, 17, 2); % [ 1-ServNo 2-RunNo, 3-FullTimeSpan, 4-MinAccpScore, 5-
MaxReturnScore, 6-ExtraMU(13), 7-MaxMU(11), 8:16 Statistics(2:10), 17-Score(12) ] , Serv-1 in
row 1

for ss= 1:15 % check for service (ss)

    BestServRun = 0; % to record the best run for service (ss)
    WorstServRun = 0;
    HighestScore = 0; % to record the highest score
    LowestScore = 1000;

    for rr=2:169 % for all runs; collect stable runs, run no 1 is not available
        if StatMatrix(ss, 1, rr) == 0 & StatMatrix(ss, 12, rr) > HighestScore % no unstable orders
            BestServRun = rr; % record the best run for service (ss)
            HighestScore = StatMatrix(ss, 12, rr); % record the highest score
        end

        if StatMatrix(ss, 1, rr) == 0 & StatMatrix(ss, 12, rr) < LowestScore % no unstable orders
            WorstServRun = rr; % record the worst run for service (ss)
            LowestScore = StatMatrix(ss, 12, rr); % record the lowest score
        end
    end % end of (rr) for all runs

    % record results [ 1-ServNo 2-RunNo, 3-FullTimeSpan, 4-MinAccpScore, 5-MaxReturnScore, 6-
ExtraMU(13), 7-MaxMU(11), 8:16 Statistics(2:10), 17-Score(12) ] , Serv-1 in row 1
    EvaluationResult1{(ss, 1)} = [ ss BestServRun StatMatrix(23, 2:4, BestServRun) StatMatrix(ss, 13,
    BestServRun) StatMatrix(ss, 11, BestServRun) StatMatrix(ss, 12, BestServRun)];
    EvaluationResult2{(ss, 2)} = [ ss WorstServRun StatMatrix(23, 2:4, WorstServRun) StatMatrix(ss, 13,
    WorstServRun) StatMatrix(ss, 11, WorstServRun) StatMatrix(ss, 12, WorstServRun)];

end % of (ss) for all services

% save settings and statistics for Best and bad run for service (ss)
save EvaluationResultsFile EvaluationResults;
% BestRun = EvaluationResult1(:,1)
% WorstRun = EvaluationResult2(:,2)
APPENDIX E

Publications


A SYSTEM OF MOBILE SERVICE UNITS (MSU)
FOR THE LARGE SCALE EVENT INDUSTRY

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Abstract

The paper highlights the importance of mobile service units (MSU) for the large scale event industry. The approach for modelling and simulation of the system (MSU) is described. The model is implemented and discussed.

1 Introduction

The large scale event industry relies on managing and maintaining large numbers of participants in a short period of time. The demand for such services is increasing due to the rise in the number of large scale events. The mobile service units (MSU) are becoming an essential part of the event industry.

2 Investigating and developing the system of MSUs

A multi-disciplinary approach is used for designing the system of MSUs. This involves the use of various models and simulations to ensure the system is efficient and cost-effective. The models and simulations are validated using real-world data and feedback from different stakeholders.

3 Preliminary modelling and control development

The preliminary models are developed using simulation tools. These models are used to test the system under different scenarios and to identify potential issues. The models are then refined and improved as necessary.

Figure 1: Shows the preliminary models for the event centre. The models are used to simulate different scenarios and to identify potential issues. The models are then refined and improved as necessary.
Figure 1 The preliminary model for the system of MSUs.

4 Modelling and controlling The System of MSUs

The preliminary model is developed and extended to a general model. The general model consists of two main parts (Figure 2). The first part models the movement of visitors from one place to another and calculates the change of demand for services over time at each location. The second part models the movement of MSUs from one location to another in order to answer the expected and current demand for services at every location. Both parts of the model consist of several separate subsystems, which interact with each other and exchange data. These subsystems are designed to be independent so that they can be developed or replaced with least interferences to other subsystems.

4.1 Modelling the movement of visitors and the demand for services

The event program (Subsystem-2, Figure 2) represents the time series of activities and events vs. their location and the number of expected participants/pilgrims. Buses updated schedule (Subsystem-3) receives the requests for bus-trips for transporting participants to new locations and produces schedule for bus trips. Due to the limited capacity of road networks, not all bus-trip requests could be answered during peak times and will be shifted to some alternative times before or after the peak. Such shift is desirable to avoid many difficulties that usually associated with peak times. Buses Back-up Schedule (Subsystem-4) keeps record of the latest bus schedule and will be executed only if Subsystem-3 fails. Subsystem-5 executes bus-schedules and generates orders for buses to move. It may change the execution of bus-schedule slightly due to the last minutes orders form the control centre (Subsystem-1). Buses movements (Subsystem-6) generate traffic volumes on roads and consume time for transportation before participants arrive to their destinations. Subsystem-7 accounts for the time needed for bus embarking. Although buses are the main transportation mode in the Hajj, Subsystem-8 accounts for other transportation modes especially pedestrians. Model-9 converts the number of buses, vehicles and pedestrians arrived to each site to population vs. time. Subsystem-9 converts the population vs. time to demand vs. time putting in consideration the effects of event programs on the demand for particular services.

Figure 2 The general model of the system of MSUs.
4.2 Modelling the movement of MSUs and the supply of services

General and special Attributes are ascribed to each type of MSU to describe their functions, characteristics, supplies, deliveries, inputs and outputs, in order to model them within the whole system. These attributes are also important for making decisions for the most appropriate MSU to be sent to a particular location. Data are stored in a matrix form where rows represent MSUs and columns represent their attributes.

According to the expected/current demand for services produced by Subsystem-10 (Figure 2) and the measures for Customer Satisfaction (Subsystem-11), the Control Centre (Subsystem-1) authorizes the MSUs Updated-Schedule (Subsystem-11) to respond and produces a schedule for the MSUs indicating locations to be served vs. time. MSUs scheduling take in consideration traffic conditions to avoid peaks and gives priority to buses movement by shifting MSUs movements to be before or after peaks. MSU Back-up Schedule (Subsystem-12) keeps record of the latest MSU's updated schedule to be executed in case of failure of the main schedule (Subsystem-11). Subsystem-13 executes the schedule by ordering MSUs to move to next locations taking in considerations any last minute orders from the Control Centre. Some delay took place before movement of MSUs for serving the remaining customers and to prepare MSUs to move (Subsystem-14). The transportation conditions (Subsystem-15) monitors bus trips (Subsystem-6) and other transportation modes (Subsystem-9) and calculates the expected transportation times at the different routes. Subsystem-16 accounts for the time elapsed before the moving MSUs reach their destinations. Preparations times for MSUs for serving at their destinations are accounted by Subsystem-17. Provided the resources for the service (Subsystem-18) are available, MSUs are now ready to serve and their service capacity are added to their destinations (Subsystem-19). MSUs supply and saved services (Subsystem-20) form the total services supply at the location. By the end of their service periods, MSUs are made available for the next job (Subsystem-21).

4.3 Controlling the system of MSUs

The outputs of Model-10 (Figure 2) for the demand of service and Models-19 & 20 are fed to Subsystem-21, which represents customer satisfaction. The availability of service when needed is one of the most important factors for customer satisfaction. If the demand for a service at a particular time exceeds the total supply of that service by a grate portion, the result is long queues and long waiting times that reduces the level of customer satisfaction. On the other hand, if supply exceeds demand by a grate portion, service providers satisfaction will be low as they provides services without enough number of customers which increases the cost of their services. This in turn would reduce customer satisfaction due to the increased prices of services.

Therefore, the ultimate goal of the control centre (Subsystem-1) is to make the right balance between demand and supply of services at the different locations putting in considerations the limitations of MSUs availability, event programs and traffic conditions.

4.4 Feed-back and feed-forward data

The different subsystems in the model exchange data directly, through the control centre, global variables or by saving to common data files. In reality, feed back-data for the behaviour of the system and its response can be gathered through various sensors, GPS, reporters, remote sensing and Intelligent Highway Systems. Geographical Information Systems (GIS) have good potential to manage the spatial data of the system and assist the predictions of demand for services at all locations. A Graphical User Interface (GUI) can be used to present and manipulate the huge amount of information about the system to assist control operators in their decision-making processes. MSU operators will receive printed updated job orders for the schedule of their own units from local supervision office.

5 Simulation of the system of MSUs

The model operates in two modes: Scheduling mode and Operation mode. In the Scheduling Mode, the model runs the whole period and simulates the execution of the first part of the model (as mentioned in 4.1) to generate the expected demand for services according to the reservations for bus trips shifted by a time delay for transportation and disembarking of participants. The generated expected demand vs. time is satisfied by scheduling MSUs to be sent to locations before its actual need by the time required for transportation and preparation. If traffic conditions are not suitable, MSUs will be scheduled for the last possible chance. The end time is determined when an MSU is not needed at that location.

In Operation Mode, the model runs in real time. Bus trips are generated according to the actual implementation of bus schedules with the latest modifications from control. Actual traffic conditions are calculated from bus trips and actual transportation times are calculated from traffic conditions. The number of arrivals is added to the population and generates the actual demand for services. Meanwhile, MSUs are sent according to the schedule and if the control centre predicts severe diversion of actual service demand from the expected demand, it takes action by altering the execution of MSU's schedule either by advancing or delaying the order to move MSUs. If extra service capacity is badly needed at some locations, the control centre sends MSUs from the reserve making least amount of changes in the main MSUs schedule.

6 Results and discussions

Different control strategies and algorithms are tried in order to develop the strategy that satisfies the needs of customers and the requirements of service providers. The algorithms are mainly conditional statements to represent the rules and conditions for requesting and releasing MSUs. Service Status (SS) is introduced to examine the quality of the algorithms. The value of SS is the difference between supply and demand for the service. Negative values for SS represent shortage of supply for the service. Therefore, one of the objectives of the control is to avoid negative values of SS whenever possible.

The first control strategy is based on an online control, where SS is monitored and an MSU is requested whenever SS decreases below specific value. One or more MSUs may be requested in advance to account for transportation time delay. Figure 3 represents some cases studies for this strategy. As shown, the values of SS are frequently become negative due to late request/arrival of MSUs at the beginning of the
demand peak. Cases (a, b and c, Figure 3) have introduced the need for another control objective to prevent the oscillation of requests and releases of MSUs in an attempt to match the demand. Case (d, Figure 3) has solved the oscillation problem by adding conditions for the minimum SS value before releasing MSUs. However, the problem of the shortage of supply at the beginning of the peak is not solved despite the different algorithms tried. This is mainly due to the delay in the response of the system for MSU transportation.

The second control strategy is based on an off-line scheduling of MSUs before the event took place. The expected demand vs. time is deduced from service providers' experience or derived from events' programs. On scheduling mode, the model runs using the expected demand making requests for MSUs whenever negative values of SS is detected. The time of MSU-request minus the expected transportation and preparation times is recorded. When a positive value of SS exceeds the capacity of one MSU, an MSU is released and made available for other locations. Figure 4 shows the scheduled MSUs supply of service that satisfies the expected demand without negative SS values. It also shows the implementation of the role of requesting the largest available MSUs first and the role of releasing MSUs on the bases of “first-come first-go” for equal opportunities to all MSUs. On operation mode, the model executes MSU schedule and sends MSUs at the specified times before the peak of service occurs and releases surplus MSUs. This control strategy is found to be appropriate for controlling the system of MSUs as it better accounts for transportation and preparations delays.

Figures 3 and 6 show the demand for services at two locations at nearby pilgrimage areas (Miraa and Arfa, which are 6 km apart) and their corresponding MSUs supply. The control algorithm responds to the various in demand by discrete supply of MSUs both in scheduling and operation modes.

![Figure 3 The trial of different control algorithms.](image)

![Figure 4 Scheduling MSUs from the expected demand.](image)

![Figure 5 The response of the system for the demand for services at Mina.](image)
7 Conclusion

The Multi-disciplinary approach used for investigating the proposed system of MSUs is found to be very helpful in understanding and developing the system both on macroscopic and microscopic scales. The analysis of the questionnaire had highlighted the requirements of service providers to be considered in the proposed system. The various designs of MSUs and their integration with urban and suburban forms had demonstrated the ability to construct the proposed system. Modelling and simulation of the system had demonstrated that the system is operational and controllable. The possibility of modeling and simulating such a system using MATLAB/SIMULINK has been demonstrated.

8 Future developments

The model will be expanded and will adopt Fuzzy Logic (an artificial intelligence technique) to assist decision making for MSUs-scheduling and control actions.

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Modelling and simulation of a system of mobile service units (MSUs) for the large scale event industry

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ABSTRACT:
A proposed system of Mobile Service Units (MSUs) is modelled and simulated for the Mega-scale event of the Hajj, where millions of visitors move about four nearby cities and the proposed MSUs will be transported accordingly to serve them. The model consists of subsystems that represent the master plan for the four cities, the events’ program of the Hajj, the MSUs, the transportation system and the control centre. Simulation results show that the proposed system of MSUs can be used successfully for the Hajj with a significant reduction in the number of units needed when compared with the fixed service centres currently in operation.

1 INTRODUCTION
The success of the large-scale event industry, which deals with managing and running large-scale events such as Olympics, depends mainly on two factors: the quality of the program, and the quality of the facilities and services provided [1]. Although, different events have different programs, they are commonly characterized by huge demand for almost the same facilities and services within a short period of time. Providing repeated fixed services at every location are costly and time consuming, while providing temporary services may not satisfy the high standards required. In another approach [2], an integrated system of Mobile Service Units (MSUs) is proposed for the Mega-scale event of the Hajj (The annual Moslem pilgrimage to Makkah, Saudi Arabia). Being mobile, these MSUs can be used at many occasions without being limited to specific location, which increases their economical feasibility and allows for higher service standards. In a previous work [3], an approach for modelling and simulation of the proposed system of MSUs using MATLAB/SIMULINK is presented and discussed. In the current paper, a more comprehensive approach for modelling the system that accounts for multi MSUs at multi locations, demand for services of the Hajj, MSUs supply of services and traffic conditions will be briefly described and discussed.

2 MODELLING THE MASTER PLAN
The new Master Plan for the cities of the Hajj [4] with its six main connecting roads is shown in fig 1(a). The control centre is presented in a simplified graphical form as shown in fig 1(b), where each loop has its own support area and passes through four accommodation zones at each of the four pilgrimage cities, giving a total of 6 support areas and 96 zones. Each zone accommodates 200,000 pilgrims/visitors giving the total capacity of 4.8 million visitors expected by year 2025 [4]. Zones are given 3 digits numbers representing city, loop and zone respectively. Since the six loops of the new master plan are almost identical with slight variations, one loop can be modelled and duplicated to account for the remaining five loops. Fig 1(c) shows the Simulink and MATLAB modelling for loop-1 and its four pilgrimage zones in each of the four cities where each zone is represented by a subsystem. The model is designed as subsystems that contain sub-subsystems in hierarchical order to organize the logic of modelling and allows for modifications. Being modular, these subsystems can be modified individually or replaced by specialized software without affecting other subsystems. The model consists mainly of two types of subsystems. The first type represents each zone of the master plan, where the interaction between demand and supply for services takes place. The second type is a subsystem representing the support zone, where movements of buses according to the events’ program are simulated and a decision making process takes place to answer the requests for MSUs from all zones.

3 MODELLING THE EVENTS’ PROGRAM
The main events during the Hajj that of concern to this paper are summarised in fig 2. The movements of pilgrims from one city to another during the Hajj as shown in fig 2(a and b) produces the rapid change of population at these cities as shown in fig 2(c). The population is measured in Pilgrim Units (PU), a unit equivalent to 50 pilgrims, which is introduced to speed
up simulation and represent the average number of passengers of a large bus. Apart from the city of Makkah, the other three cities are almost uninhabited except during the Hajj. This makes the variation of population at each zone changes from zero to 4000 PU (200,000 pilgrims) and back to zero within short period of time as shown in fig 2(c) for a typical zone from each city. The population of the residents of Makkah is not shown in the curve since they have their own services and only the additional population due to arrival of visitors is considered. Events program are translated to variation of population vs. time and saved in a data file to be called during simulation. Simulation is set to cover the period from day 7 to day 13 of the month of the Hajj where most events of the Hajj take place. The simulation step is set to 0.025 hr (1.5 minutes) giving a total of 6720 simulation steps for the 7 days period.

![Diagram](image)

**Figure 2: The main events of the Hajj that considered in the model**

4 MODELLING DEMAND FOR SERVICES AND MSUs SUPPLY

From a survey conducted during the Hajj 2000, 44 types of services are found to be suitable to be developed as MSUs. For simplification, these types are grouped into 16 MSU-groups of similar service capacity and importance. This allows that one service-group can be evaluated at a time every simulation step and all services-groups are re-evaluated every 24 minutes. The number of units needed to serve the whole population of each zone is identified using an approach similar to that used by the master plan where space requirement is defined for each type of service [4]. Accordingly, the service capacity for these MSUs-groups are set to be from 267 to 4000 PU that satisfy the need of 6.6% to 100% of maximum population of a zone respectively.

Inside each zone as shown in fig 3, the signal coming from the control centre at support zone, is separated into its main signals and distributed to subsystems representing the arriving and departing MSUs and buses. MSUs movements are represented by a signal of (16x16) matrix, where each row corresponds to a particular zone and each column to a particular MSUs-group. In the simulation, the initial conditions assume 100% MSUs at Makkah. The population of a particular zone is estimated from the total number of loaded buses that entering and leaving that zone. This is because the master plan depends totally on large buses

for transportation [4]. The number of pedestrians entering or leaving that zone can be estimated using an appropriate automated techniques such as infrared counters [5] and added to the total population. The service capacity available at a zone can be calculated from the number of existing MSUs. Finally the MSU-request subsystem issues request to control centre, using a specially developed fuzzy logic controller, for returning an existing un-needed MSU or requesting an additional one based on service conditions inside that zone.

![Diagram](image)

**Figure 3: Inside a typical subsystem 'Zone'**

5 CONTROLLING THE SYSTEM OF MSUs

The control centre at the support area has six main subsystems as shown in fig 4. The 'Event Programs' subsystem represents the events of the Hajj and produces the variation of population at the different zones as described before. These data are fed to subsystems that generate orders to buses to transport pilgrims to and from zones. The subsystem 'Traffic volume' calculates the traffic volume due to the movements of buses and MSUs at every simulation step. The subsystem 'MSUs Availability' evaluates the remaining MSUs available at the support zone. The subsystem 'MSUs Movements' represents the core for modelling and decision making for the movements of MSUs. It responds to the requests for services from all zones within the loop. This is done by making decisions and issuing orders to return unneeded MSUs and to send MSUs to needy zones. MSU-Request signals form all zones are separated and fed with other inputs of MSU availability, current traffic volume and the expected traffic volume in the foreseen future to subsystems which re-evaluate these requests using FLC. A specially written function sorts these re-evaluated MSUs-requests then issues orders to return and to send MSUs according to their relative importance. To assure smooth traffic flow, the control insures that the total traffic in the main loop should not exceed the traffic volume capacity of 750 large vehicle (LV)/lane/hr [4] at any time. A transport delay block is used to represent the time needed for transporting MSUs from one zone to another.
6 SIMULATION RESULTS AND DISCUSSION

Figure 5 shows the response of the system using the current model, for the demand for services of two MSUs groups. Grope-16 shown in fig 5(a) are of medium service capacity of 1000 PU, i.e. 25% of population. Therefore four batches of this group fulfills the needs for the whole population of a zone. The demand for this service is fairly matched by MSU supply for service, putting in consideration that existing MSUs can operate over their maximum service capacity for short periods of time to cover any shortage of services. Due to the high discrete value of the capacity of this group, some compromises are made as shown at points (1, 2 and 3) by accepting slight over and under supply of services.

On the other hand, MSU group-3, shown in fig 4(b), is of very low service capacity of 444 PU, i.e. one batch serves only 11% of the population and 9 batches are needed to serve the whole population of a zone. Although the increased number of batches gives the control higher flexibility to match the demand curves as seen at points (4) and (5); the large number of their units restricts transporting them during peaks of traffic which causes severe shortage of services in some incidents as shown at point (6).

Simulation results show that no additional MSUs will be needed. This is a significant reduction in the total capacity of services needed for the four cities from 400% in case of using fixed service centres (repeated 4 times in the four city) to only 100% of the number of visitors by using the proposed system of MSUs. Simulation results also show that the additional traffic due to the movement of MSUs can be controlled and limited to less than the maximum road capacity, which assures smooth traffic flow. The priority is given to bus traffic for transporting pilgrims and only the excess road capacity is used to move essential MSUs.

7 CONCLUSIONS

The modelling of the whole system is made by modelling each of it’s main components. An online control of the orders to move MSUs is used to provide just-in-time services, wherever needed, which reduce the total number of MSUs and increase their profitability without noticeable reduction in the supply of services. Simulation results shows that the proposed system of MSUs can be used successfully for the Mega-event of the Hajj.

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REFERENCES


Investigation of an automated system for estimating people's density using infra-red thermal imaging

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ABSTRACT
There is a need for on-line information regarding people's densities and numbers when organising mega events. This is to enable the decision makers to have the most precise and updated information in order to take the right decision regarding safety issues, services, organisation of people and traffic. Human-based monitoring system could include high percentage of human error due to personal perception, change of view angle and tiredness. Therefore, for on-line monitoring system there is a need for automation. This study investigates the use of low-resolution infrared technology combined with video images as a tool to estimate people's numbers and densities. The initial results found demonstrate that the suggested infrared techniques are very promising for automated monitoring systems.

1 INTRODUCTION
The Haji, the annual Muslim pilgrimage to Makkah (Mecca), Saudi Arabia, is a mega-scale event that currently attracts more than two millions of visitors every year from all over the world for about two weeks. It is described as the biggest annual mass movement of people on the planet [1], and it is expected to attract 4.8 millions by the year 2025 [2]. Many areas of high density of people could be found during the Haji. Particularly in the Holly Grand Mosque of Makkah where more than 750,000 visitors gather at one single formation and in Al-Jamarat Bridge where more than 120,000 pedestrians pass over a single bridge every hour during peak times. The estimation of the number of people participating in such events is essential for managing and providing appropriate services. Estimation of the densities of people at the different locations of such events is essential for safety precautions and utilization of space. This paper presents a novel and a cost-effective approach for monitoring the critical areas in the Haji using infrared technology. The paper presents the concept of condition monitoring of Haji activities using thermal images and some of the results found during the Haji 2002.

2 CONDITION MONITORING OF HAJJ ACTIVITIES
It has been concluded that the success of the Haji depends mainly on the success of the facilities and services provided [3]. In order to control a proposed system of Mobile Service Units (MSUs) for the Haji, reference [4], has indicated the need to use remote sensing for estimating the number of people at the different locations. The use of infrared technology to monitor people's density could provide an essential advantage for the full control of the places of the Haji including the full control of the transportation systems, the services for people, insure high levels of safety and provide an optimum organisation of the complete system. Figure 1 presents an overview of the proposed monitoring system. By remotely monitoring the critical areas and the Haji activities, information can be gathered and fed into a central control room where computers can then be used for on-line analysis to measure people's density. This will allow an approximation of the number of people in every sector or area. The estimated numbers can be used to evaluate the efficiency of services within those areas, and hence sending mobile service units when and wherever needed [4]. Also the intelligent system should be able to provide the necessary prognosis by predicting the expected number of people in a particular area as a function of time to provide futurist planning, scheduling mobile service units and maintaining people's safety.

3 INFRARED THERMOGRAPHY
Objects transfer heat in three ways: conduction, convection and radiation. Conduction is the transfer of heat energy through solid bodies. Convection is the transfer of heat through the movement of a fluid (e.g. air) and radiation is the transfer of heat energy via electromagnetic radiation (infrared) emitted by the object [5]. The Infrared thermal imager senses infrared radiation which is proportional to the temperature of an object. The Imager converts the infrared radiation into an electric voltage which is then digitised and transferred to a computer system. It can then be used to represent the readings as temperatures and display images. The common application of infrared thermography is to identify hot and cold areas within an image. However, since human temperature is expected to be about 37°C. The infrared technology can be used to estimate people's numbers within a specific area based on the fact that every individual can be considered as a heat source. When looking at people's numbers from a distance, the more people you have the more heat is generated from them which can be detected through infrared cameras.

4 INITIAL EVALUATION OF THE APPROACH
An initial experimental work is conducted to investigate the suggested methodology of using low cost infrared system for estimating people's density. In the test, Figure 2, different number of people is monitored. The results showed that there is a significant correlation between the infrared radiation generated and the number of people in the infrared picture.
5 THE EXPERIMENTAL WORK

The experimental work was performed during the Hajj 2002. Figure 3 presents the two main locations of interest, Al-Jamarat bridge and Makkah's Grand Mosque. The sensor used was an IRISYS infrared imager and a video camera to record the visual images taken. The IRISYS thermal imager used in this work is pyroelectric. In a pyroelectric detector, the temperature change of the element causes a change in the charge present on the device electrode. The detector does not require cooling, however, they require a constantly changing image signal using a chopper. The IRISYS infrared thermal imager is said to break new ground in size, flexibility, ease of use and cost [6]. The infrared imager has a 16x16 pixels resolution. This low resolution, hence less amount of data to process, allows on-line analysis of data in high speed and the application of artificial intelligence for decision-making.

Figure 3: The locations were the research work was performed: The pedestrian bridge of Al-Jamarat (the symbolic stoning of the devil) (a) and Al-Masjid Al-Haraam (Makkah's Grand Mosque) (b).

Figure 4: Al-Jamarat thermal image

Specially developed on-line Matlab software has been used for data capturing and analysis. The software is able to communicate with the imager via RS232 to import the data as Matlab variables for on-line analysis. The software supports many options for data presentation using 3D surfaces and colour options as well as exporting images as jpeg and bmp format. The software can also capture a sequence of time-elapse infrared images and save them into the PC for comparison with the video images for synchronisation and further analysis.

6 RESULTS AND DISCUSSION

Figure 4 presents a thermal image and the associated visual image of the pedestrians on Al-Jamarat Bridge. The people access the bridge from the right hand side and leave either from the sides of the bridge or from the far left end. Figure 4 shows that the density of people coming from the right side (2), to Al-Jamrah Al-Kubra (1) is much greater than the left side the were people leave. Some localised high density, (3), is normally occurs when a group of people perform the activities together. Signs, (4) and (5), appears as a cooler areas within the image. It should be noted that the infrared images obtained have a 16x16 pixel resolution. The images shown have been processed by interpolation to a 128x128 pixel size. Any image processing work is carried out on the raw images, as no extra data is present from the interpolation, however, it aids visualisation for humans. Figure 5 presents a 3D surface of the infrared information shown in Figure 4.
Figure 5: A 3D surface of the heat pattern of people queuing around Al-Jamrah Al-Kubra

Figure 6 presents the thermal image and the associated visual image of Makkah’s Grand Mosque and the people walking counter-clock-wise around the Ka’ba (1). The left lower side of the image shows high density of people since people normally start and end their walk near areas (2a) and (2b). The delay in walking speed in the high-density areas causes a low density later down stream (3). Maqam Ibrahim (Abraham) (4) appears as a cooler area in the infrared image since it is a small building with no people. Other areas, such as (5), appear less dense than the lower part of the infrared image. The areas adjacent to the Ka’ba (1) have very high density of people, the area between (1) and (3). The interpolation process causes the densities on the borders of the regions to have an average level. However, by looking at a 3D surface presentation of the thermal image, as shown in Figure 7, the high density level of the border areas becomes much clearer.

Figure 6: The thermal image of Makkah’s Grand Mosque

7 CONCLUSIONS AND FUTURE WORK

The paper presented a novel and a cost-effective approach for monitoring the critical areas in the Hajj using infrared technology. The initial results demonstrate that low-resolution infrared imagers can be used for monitoring people’s density. It is found that one infrared imager of 16x16 pixels could monitor large areas from a distant location. This allows a cost-effective solution for estimating the number of people at different locations. The use of infrared technology to monitor people’s density could provide an essential advantage for the full control of the places of the Hajj including the full control of the transportation systems, the services for people, insure high levels of safety and provide an optimum organisation of the complete system. Further work is planned to identify the sensitivity of this approach and the effects of weather conditions on the quality of information. Artificial intelligent systems such as Novelty detection, Neural networks and fuzzy logic will be used to gather and integrate the sensory information together for detecting and predicting peoples numbers, and take the right decision regarding the current/expected level of safety, services, management, pollution, etc.

8 REFERENCES

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Fuzzy logic control for mobile service systems with limited resources

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Abstract: It is common to control systems or plants through changing the values of their inputs in continuous or small discrete steps to achieve gradual change of the performance of the plant under control. However, when changing the inputs can only be achieved in large discrete values, problems arise on achieving stability of the plant under control as such large discrete changes in inputs cause large overshoots and oscillations at the outputs. More difficulties arise when multiple plants are competing simultaneously for limited resources of such large discrete values.

This paper describes an approach for controlling such plants. The case study presented is to control a proposed system of mobile service units (MSUs) to be used in a mega-event, the Hajj, where different locations/zones will be competing simultaneously for a limited number of MSUs in order to provide adequate services for their continuously changing number of visitors. These MSUs are of high discrete values such that their provision or removal generates a significant change in the performance of the system.

Fuzzy logic controllers (FLCs), representing each zone, are developed for issuing requests for MSUs based on their local situations. These requests are evaluated by the control centre using other sets of FLCs to consider global situations. An algorithm is used to respond to these evaluated requests according to their relative importance and issues orders to MSUs to move to the right zone at the right time to provide the appropriate amount of service for the existing number of visitors or what can be called ‘just-in-time MSUs’ (JIT-MSUs). Simulation results show that such a system can be controlled using the approach suggested by this paper and the response of the system varies with the values of its discrete inputs. Some conclusions and recommendations are drawn for the appropriate discrete input values and their control settings. The procedure for evaluating the different simulation runs for the different control settings is also presented.

Keywords: fuzzy logic controllers, discrete inputs of high values, competing plants, limited resources, decision making, artificial intelligence, services for the Hajj

1 BACKGROUND

The Hajj, the annual Muslim pilgrimage to Makkah, Saudi Arabia, is a mega-event that attracts millions of visitors/pilgrims from all over the world for about two weeks. In order to host the 4.8 million visitors expected by year 2025, a new master plan [1] is proposed for the four cities of the Hajj: Makkah, Mina, Muzdalifah and Arafat. The concept of the master plan is based on six main roads or loops, each loop serves four zones at each city and each zone accommodates 100,000 pilgrims, giving a total capacity of 4.8 million.

Due to the short stay of pilgrims at the four cities during the Hajj (Fig. 1), which lasts for a few days every year, it would be too expensive to repeat fixed service centres at the four cities, as it makes the total service capacity enough for 19.2 million while serving only 4.8 million at a time. Therefore, in order to reduce the cost and improve the quality of services provided, a system of mobile service units (MSUs), originally suggested...
2 THE CONTROL PROBLEM

The mass movement of visitors between the different zones at the four cities shifts demand peaks for services from one zone to another and need to be satisfactorily fulfilled by MSUs. The system to be controlled is the process of providing services for pilgrims during the Hajj using MSUs. The demand for services (or the controlled variable) is continuous while the response of the control, by sending or returning MSUs (or the manipulated variable), can be only achieved in large discrete values, which cause severe overshooting and disturbance to the status of services provided (or the error).

3 THE DEVELOPED CONTROL FOR THE SYSTEM OF MSUs

Fuzzy logic controllers (FLC) are chosen to control the system of MSUs due to their ability to represent the verbal control rules of service providers, to deal with the non-linearity of the system and to demonstrate their high tolerance to imprecision without the need for an explicit mathematical modelling of the system [5, 6]. FLCs showed successful implementation in applications that, to some extent, have some similarity in nature to parts of the system of MSUs, such as controlling an automated goods transporting device in a distribution centre [7], controlling multiple vehicles [8] and solving the problem of period length selection [9]. Decentralized and hierarchical control are used to organize the control of the system. It is used in reference [10] to control a large-scale discrete event system and in reference [11] to show how a coordinator controls the lower-level supervisors in the form of supervisor cooperation.

The control system of the system of MSUs is derived from the general model of the system [12] and consists of three stages, as shown in Fig. 2. In stage 1, each zone evaluates its needs for MSUs based on its local situation and issues an MSU request to the control centre using a specially developed FLC 'Request'. These requests represent the microscopic point of view of each zone for their demand for a particular service. In stage 2, all MSU requests from all zones are evaluated simultaneously by the control centre using another specially developed FLC 'Evaluation' assigned for each zone, used to consider the current situations at the support zone and the global situations at the system as a whole.

In stage 3, a specifically written function 'MSUOrders', based in the control centre, sorts the evaluated MSU requests according to their relative importance and then executes the appropriate action controls, based on some control parameters, by releasing MSUs from zones that do not need them, sending MSUs to zones that are desperately in need of them or taking no action. By this response from the control centre, the closed control loop is completed.

3.1 The first stage: issuing an MSU request

A subsystem located inside each zone contains the fuzzy logic controller 'Request', which issues a score for requesting an existing MSU (10 to 0) or a score for requesting an additional one (0 to 10) based on service conditions inside that zone fed as inputs (fuzzy variables) to the controller. The fuzzy variables, their fuzzy membership functions (MFs) and the output of the FLC 'Request' are represented in tabulated form in Table 1.

Service status is defined in this paper at the difference between supply and demand for service. The first fuzzy variable 'ServiceToCapacity', representing the ratio of the current service status to MSU service capacity, is given three MFs: 'NegativeVeryHigh', 'OK' and 'PositiveVeryHigh' for describing service situations of under-supply, acceptable and over-supply respectively. The second variable 'PopulationChange' is given three MFs: 'NegativeVeryHigh', 'NoChange', 'PositiveVeryHigh' for describing situations of decreases, no change and increases in the population respectively. When these two variables are evaluated, they produce the result of the FLC 'Request' of the degree of need for an additional MSU, namely 'Low', 'High', 'Urgent' and 'TopPriority'.
Figure 4 represents one case study for the evaluation process for the FLC 'Request' given for demonstration. The first input 'ServiceToCapacity' has a value of -0.5, which indicates that there is a relatively high shortage of service provided, which is equal to half the capacity of an MSU. This value falls only in the region of 'NegativeVeryHigh' for this input; therefore it fires the first nine rules only. The second input 'PopulationChange' indicates that pilgrims are leaving that zone at a relatively slow rate of -0.6, which has intersections with the three MFs for this input at different values; therefore, some degree will be inherited from nearby rules. The third input 'FutureNeed' has a value of -0.3, which indicates that, after a certain time defined by 'Lookahead', if no action is taken, it is expected that there will be still some shortage for service but less than the current situation. The nine rules contribute in some degree or another in the decision making for this case, which can be read as follows: 'Currently there is a shortage in the service provided but pilgrims are leaving the zone and the shortage of the service is expected to be better in the near future; therefore, the resultant evaluation/ request is: there is no severe need for an additional MSU now, but if it could be provided that will improve service in the current stage.' This evaluation is presented in the score of 2.76 (out of 10) for 'MSU-request', which will be reported to the control centre.

3.2 The second stage: evaluation of MSU requests from all zones

Requests received from all zones are evaluated simultaneously at the control centre using the FLC 'Evaluation', which considers another set of factors affecting the whole system fed to the controller as inputs. These inputs, their MFs and the rules for this controller are presented in Table 2 and Fig. 5. The first input is the 'MSU-request', received from the zone that this controller evaluates, which is limited to the range -10 to 10 and given five MFs: 'NeedLow' and 'NotNeeded' for unneeded MSUs, 'NoRequest' for good conditions that have no need for returning or sending MSUs and 'HighRequest' and 'Urgent' for the need for an additional MSU. The second input is 'MSU-availability', limited to the range 0 to 1 and given two MFs, 'Available' and 'Rare', to indicate whether too many MSUs are available at the support zone; therefore, most requests can be answered or very few can be answered so only top priority requests can be dealt with. The third input 'CurrentTrafficVolume', limited to the range 0 to 65, reflects the current traffic volume in the loop and is given two MFs: 'TrafficLow' to indicate that traffic volume is low so many MSUs can be allowed to move and 'TrafficHigh' to indicate that not much room is left for moving MSUs. The fourth input is 'FutureBusTraffic', limited to the range 0 to 65, given two MFs to describe the expected traffic volume due to the movement of pilgrims' buses, where 'FewBuses' indicates that in the near future there will be few buses on the road so many MSUs can be moved at that time and 'ManyBuses' to indicate that not many MSUs will

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Fuzzy inputs and output for the FLC 'Evaluation'</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CurrentTrafficVolume</strong></td>
<td><strong>TrafficLow</strong></td>
</tr>
<tr>
<td><strong>MSU-request</strong></td>
<td><strong>MSU-availability</strong></td>
</tr>
<tr>
<td>NotNeeded</td>
<td>Rare' Available'</td>
</tr>
<tr>
<td>NoRequest'</td>
<td>Rare' Available'</td>
</tr>
<tr>
<td>Urgent'</td>
<td>Rare' Available'</td>
</tr>
<tr>
<td>NeedLow'</td>
<td>Rare' Available'</td>
</tr>
<tr>
<td>HighRequest'</td>
<td>Rare' Available'</td>
</tr>
</tbody>
</table>
be allowed to move after a certain time due to the mass transportation of pilgrims; therefore it should be better to approve that request now.

In order to demonstrate the evaluation process for the FLC Evaluation, Fig. 6 shows its implementation for one case study. An 'MSU-request' with a score of 4.9 (out of 10) is issued from a zone, indicating a relatively high need for an additional MSU, which fires the rules that have MSUs containing this score. The second input 'MssAvailability' has a value of 0.3 (out of 1), which indicates that relatively many MSUs are currently available at the support zone. The third input 'Current TrafficVolume' with a value of 50 (out of 75) reports that roads are currently crowded, while the fourth input 'FutureBusTraffic' with a value of 22 (out of 65) expects that in the near future not many buses will be on the road. The situation can be read as follows: A particular zone has a relatively high need for an additional MSU, but there are few available in the support zone and the roads are too busy now but are expected to be better after some time; therefore, the decision is to wait for better traffic conditions after a while.

3.3 The third stage: testing orders to sending and returning MSUs

The specially written MATLAB function 'MssOrders' sorts the evaluated MSU requests and then issues orders to return unneeded or slightly needed MSUs and sends MSUs to zones according to their relative importance and the global situations for the system as a whole. The inputs for this function are the evaluated 'MSU-request' from all zones, the number of MSUs available at the support zone, the Instant-Acceptance-Score, the Min Acceptance-Score, the Max-Return-Score, the Instant-Return-Score, Traffic Volume and the Batch-size for the MSU service group under investigation. The algorithm for the 'MssOrders' function can be summarized as follows in conjunction with Fig. 7:

1. Return MSUs from zones scoring below the Instant-Return-Score as they are not needed any more. Stop returning them if the traffic volume approaches the maximum limit, but still make them available for urgent needs.
2. Send MSUs urgently to all zones scoring above the Instant-Acceptance-Score since they need them badly, even by returning MSUs from least needy zones if no MSUs are available at the support zone. Stop sending them if the total traffic volume for buses on the road and MSUs to be sent exceeds 75 for the large vehicles/simulation step.
3. Send MSUs to the top 10 highest remaining needy zones, in descending order, scoring above the Min Acceptance-Score and, if necessary, return MSUs from the least needy zones, in ascending order, scoring below the Max-Return-Score, provided that it does not contradict the previous 10 orders. In both cases, stop if the total traffic volume exceeds 75 (large vehicles/simulation step)
4. Take no action for zones scoring above the Max Return-Score up to the Min Acceptance-Score as these zones are in balance between demand and supply of services and sending or releasing MSUs from them will disturb that balance.

4 SIMULATION RESULTS AND DISCUSSION

The simulation is set to fixed discrete steps of 1.5 minutes and covers the period from the start of day 7 to the end of day 13 of the month of the Hajj where most activities take place. The different types of MSU are grouped into
16 groups of similar service capacity and close ranks for speeding up simulation. Each simulation step evaluates one MSU group at a time and the whole 16 groups are re-evaluated every evaluation cycle of 16 simulation steps. The simulation is set to run at different control settings for 'Lookahead times', 'Max-Return Score' and 'Max-Acceptance Score', giving a total of 168 runs. The selection of the ranges for these values are based on previous preliminary simulation runs [12] and are expected to provide acceptable performance for the system.

The discussion starts with defining the stability of the system of MSUs and then presents the procedure for evaluation of simulation runs and the criteria for selection of the appropriate control settings. The main discussions will be based on identifying the appropriate service capacity for MSUs that satisfies the demand for services within the constraints of the system.

4.2 Evaluation of simulation results

The process of evaluation of the 168 simulation runs is based on multiple stages. In the first stage, any control settings that issue contradictions within the 16 evaluation cycles are rejected. Although the system is made stable for 10 evaluation cycles by the algorithm mentioned before, the rejection is based on the tendency of the system to change status as soon as restrictions are removed. It is found that no single setting can fulfill this condition for all types of MSUs at the same time (Table 3). This is due to the high variation in service capacities of the MSUs, ranging from 13.3 to 200k inhabitants/glimpsers, showing that appropriate settings for an MSU of low service capacity are not necessarily suitable for an MSU of high service capacity. Therefore, each MSU service group is evaluated separately in order to find out the appropriate control settings for it. When operational, the control centre should use the relevant appropriate control settings for every MSU group under evaluation.

In the second evaluation stage, statistics are calculated for every run (Table 4) in order to present some important issues for determining the appropriate settings for controlling MSUs. The value of the 'Mean-of-Service-Status' presents the overall average of service status for a particular service group while the value of the 'Standard-deviation-of-Service-Status' presents how the values of over- and under-supply periods differ; therefore, the closer their values are to zero the better the level of service achieved. The value of the 'Worst-Under-supply-Peiod' presents the period of the worst incident of shortages of service achieved during simulation and the value of the 'Sum-of-Under-supply-Periods' presents the accumulated shortage of service provided; therefore, one of the objectives of the control should be to minimize their values. The value of the 'Sum-of-Under-supply-Periods' is used to present the capacity of services provided but not consumed, which is considered as an economical loss to service providers; therefore, the aims of the control should include minimizing this value for higher efficiency. The value of the 'Maximum-Number-of-MSUs' presents the MSUs resources needed to achieve an acceptable level of services; therefore, reducing its number reduces the capital cost of the system, which is considered as one of the main objectives for using MSUs.

In the third evaluation stage, these statistics are used to compare all runs using a simple FLC for each measure. Each controller has two MPs representing the two extremes of the best and the worst MSUs and the total score is the average of the outputs of these controllers. The total score gives the 'goodness of each setting relative to others' (Table 4). Finally, graphed for each group with the highest scores are plotted, compared and evaluated visually. If an unsupervised behaviour such as short intervals between sending and receiving MSUs or long periods of under- or over-supply is detected, the next highest score is plotted and evaluated, and so on until the appropriate response is found. Table 4 also shows the appropriate control settings selected for some MSU groups and their statistics.

4.3 MSUs of 'Very-high-service-capacity' and 'High service capacity'

MSUs of 'Very-high-service-capacity' (VHSC) of 200k inhabitants, such as MSU group 8 shown in Fig. 8, row 1, require only one unit to serve the whole population of a zone. Therefore, it is either provided to a zone or not. When provided, it fulfills all its needs for that service whatever the population; however, for a low population, the unused service capacity for that unit is reflected as periods of over-supply of the service (Fig. 8, points 1, 2, 4 and 5). On the other hand, if that MSU is removed, the shortage appears as a period of under-supply even for a low population (Fig. 8, point 3). It can also be seen in Fig. 8, point 4, that although the first peak of zone 211 reaches less than 100k inhabitants, or half the capacity of one MSU of group 8, an MSU was needed to cover that need since its absence would have created a severe shortage of service. This explains the need for the 200 per cent additional MSUs (a total of three VHSC MSUs for every four zones) at bat. It can be concluded that using VHSC MSUs does not make such reduction in resources for the Hajj compared with fixed service centres, apart from the ability of using them somewhere else outside the Hajj.

Table 3: Number of runs (out of 168 runs) that are considered stable for 11 evaluation cycles

<table>
<thead>
<tr>
<th>MSU group</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity (inhabitants) (k)</td>
<td>100</td>
<td>100</td>
<td>22.5</td>
<td>66.7</td>
<td>50</td>
<td>20</td>
<td>25</td>
<td>200</td>
<td>13.4</td>
<td>16.7</td>
<td>20</td>
<td>20</td>
<td>100</td>
<td>15.4</td>
<td>200</td>
<td>50</td>
</tr>
<tr>
<td>Stable runs</td>
<td>168</td>
<td>168</td>
<td>64</td>
<td>168</td>
<td>168</td>
<td>49</td>
<td>163</td>
<td>13</td>
<td>8</td>
<td>36</td>
<td>14</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>168</td>
<td>168</td>
</tr>
</tbody>
</table>

Table 4: Statistics and evaluation of simulation results for selected MSU groups and their control settings

<table>
<thead>
<tr>
<th>MSU group</th>
<th>8 (Public relation)</th>
<th>13 (Transportation, food, shelter)</th>
<th>4 (Civil defense, police and medical services)</th>
<th>5 (Information and distribution)</th>
<th>7 (Food selling)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity (inhabitants) (k)</td>
<td>100</td>
<td>100</td>
<td>22.5</td>
<td>66.7</td>
<td>50</td>
</tr>
</tbody>
</table>


Table 3: Number of runs (out of 168 runs) that are considered stable for 11 evaluation cycles

| Capacity (inhabitants) (k) | 100 | 100 | 22.5 | 66.7 | 50 | 20 | 25 | 200 | 13.4 | 16.7 | 20 | 20 | 100 | 15.4 | 200 | 50 |
| Stable runs | 168 | 168 | 64 | 168 | 168 | 49 | 163 | 13 | 8 | 36 | 14 | 16 | 16 | 16 | 168 | 168 |

Table 4: Statistics and evaluation of simulation results for selected MSU groups and their control settings

<table>
<thead>
<tr>
<th>MSU group</th>
<th>8 (Public relation)</th>
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<td>Capacity (inhabitants) (k)</td>
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<td>100</td>
<td>22.5</td>
<td>66.7</td>
<td>50</td>
</tr>
</tbody>
</table>
for the control (Table 4). The 'Total-under-supply' is worse than those of HSC and VHSC MSUs but can still be acceptable relative to the service capacity for MSU group 4. The most important improvement is the need for no additional MSUs (0 per cent) compared with 50 and 300 per cent for HSC and VHSC MSUs respectively, which reflects higher efficiency and utilization of MSUs for the Hajj.

Another MSC MSU to be discussed is MSU group 5 shown in Fig. 9, row 2, which has a service capacity of 1000 PU (pilgrim unit) (25 per cent of population, i.e. 50,000 inhabitants). By comparing it with MSU group 4 (Fig. 9, points 1 and 2), it can be seen that the response is improved as the supply curves match the demand curves better at zones 111, 211 and 411. This is due to the lower service capacity of MSU group 5, which gives the control four units to manipulate instead of three. Only at zone 311 does MSU group 5 show a region of under-supply (Fig. 9, point 3). This shortage is due to the low amount of extra demand but is not enough to justify sending additional MSUs of group 5, although it is already covered by the higher service capacity of MSU group 4.

It should be mentioned that any shortage of services at the beginning of demand curves may not be considered a serious problem since newly arrived pilgrims will spend some time settling down before they start looking for services. Also, a slight shortage of services, relative to the total capacity of existing MSUs, may not be considered a serious problem, since the existence MSUs can operate above their nominal capacity for short periods of time. This is usually acceptable in a service industry since service providers can handle the additional demand for services by operating above their nominal service capacity for short periods of time and customers usually accept that they will have to wait a bit longer to be served during peak times.

4.5 MSUs of 'Low-service-capacity' and 'Very-low-service-capacity'

Figure 10, row 1, represents the response of the control to the demand for MSU group 7. This group has a low service capacity (LSC) of 25k inhabitants (12.5 per cent of the maximum population); therefore, eight units/batches are needed to fulfill the needs of the maximum population of any zone. From Fig. 10, it can be seen that the supply curve matches the demand curve better than HSC MSUs, especially for low demand peaks (Fig. 10, points 1 and 2). However, some delay in the response is noticed at the beginning of the demand curve in zone 311 (Fig. 10, point 3), which resulted in some shortage of service at that time. This delay is due to the high number of LSC MSUs needed to satisfy the increasing demand, while not all requests were approved due to the high traffic volume for transporting pilgrims from zone 411 to zone 211 during that period.

MSU group 9 has a very low service capacity (VLSC) of only 13.3k inhabitants (6.7 per cent of the maximum population). Initially, it was expected that such a low service capacity would provide the control with high flexibility to match any low variation in demand. However, due to the traffic limitations, not all requests for MSUs can be answered. Figure 10, row 2, shows the

MSUs of 'High-service-capacity' (HSC) of 100k inhabitants (50 per cent of the maximum population of a zone), such as MSU group 13 shown in Fig. 8, row 2, are found to give better results compared with VHSC MSUs such as MSU group 8 discussed above. These improvements can be seen in terms of less over-supply, lower values for mean and standard deviations and, most importantly, in the reduction of the additional MSUs from 200 to 50 per cent respectively.

4.4 MSUs of 'Medium-service-capacity' (MSC), such as MSU group 4 shown in Fig. 9, row 1, that have a service capacity of 66.7k inhabitants (33 per cent of the population), show better results compared with HSC and VHSC MSUs of Fig. 8, discussed above. Although the 'Minimum-under-supply' is worst, the 'Mean-of-service-status' and the 'Standard-deviation' are reduced dramatically, reflecting a better homogeneous response.
good match between service demand and MSU supply in most zones, except at zone 311, where the delay for sending enough MSUs resulted in a severe shortage of service for a relatively long time (Fig. 10, point 5). Delays occurred also in releasing unneeded MSUs from zone 411 (Fig. 10, point 4), even though they were badly needed for zone 311, due to the high traffic volume at that period.

5 CONCLUSION

An approach for JIT-MSUs is shown as feasible to control the proposed system of MSUs for the Hajj, through an online control of the orders to move MSUs to provide the right services at the right place at the right time, achieving higher efficiency and utilization of resources.

Intelligent FLCs were used, on a microscopic scale, to evaluate the situations at every zone and to issue requests for MSUs. Another set of FLCs was used by the control centre to evaluate these requests from a macroscopic point of view in order to account for other conditions relating to the system as a whole. Since different zones compete for the same discrete limited resources, the control centre sorts these evaluated requests and issues orders according to their relative importance and the control parameters. This evaluation process, using relative scores, was found to be beneficial in managing/controlling MSUs and made the search for optimum settings for the FLCs subcritical since the same rules applied to all the zones/plants simultaneously. Modelling and simulation of the system of MSUs was found to be a very effective tool in developing the control rules and evaluating their effects on the level of services provided and traffic conditions without disturbing the mega-event of the Hajj.

MSUs of medium service capacity ranging from 50 to 66.7k inhabitants (25 to 33 per cent of the population) were found to be very suitable for use in the proposed system. They require no additional units, do not affect traffic volume significantly and were found to be stable to control. Lower service capacity MSUs down to 25k inhabitants are also suitable to some extent as they require no additional units and their performance can be improved by making use of external spaces in order to increase their service capacity, hence reducing the number of units. Very-high service capacity MSUs need to be reduced in their capacity and increased in their number of units to increase their efficiency. MSUs of very-low service capacity should be used sparingly, by increasing their service capacity, to allow for their transportation during peak times.

In general, the approach suggested by this paper, the analysis, the evaluation procedure and its recommendations can be applied to similar situations where different plants/systems are competing for the same resources/machines that can only be provided in high discrete values.

ACKNOWLEDGEMENTS

The authors are grateful for the financial support of the Custodian of the Two Holy Mosques Institute for Hajj Research, Unam Al-Qura University, Makkah, Saudi Arabia.

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Modelling and simulation of a system of Mobile Service Units (MSUs) for the large-scale event industry

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ABSTRACT: A proposed system of Mobile Service Units (MSUs) is modelled and simulated for the Mega-scale event of the Hajj, where millions of visitors move about four nearby cities for about two weeks and the proposed MSUs will be transported accordingly to serve them. The model consists of subsystems that represent the master plan for the four cities, the events' programme of the Hajj, the MSUs, the transportation system and the control centre. Simulation results show that the proposed system can be modelled and the MSUs can be used successfully for the Hajj. A significant reduction in resources, compared with the fixed service centres currently in operation, is achieved using the proposed MSUs.

1 INTRODUCTION

The large-scale event industry deals with managing and running large-scale events or hallmark events such as the Olympics, large conferences and meetings, conventions and mass occasional tourism. It has great impact on the hosting countries and cities [1-5] and necessitates great deal of planning and management [6-11]. The success of such large-scale events, depends mainly on two factors: the quality of the programme, and the quality of the facilities and services provided [7, 12]. Although different events have different programmes, they are characterized by huge demand for almost the same facilities and services within a short period of time. Providing repeated fixed services at every location of such short term events are costly and time consuming, whilst providing temporary services may not satisfy the high standards required. In another approach [13], an integrated system of Mobile Service Units (MSUs) is proposed for the Mega-scale event of the Hajj; the annual Muslim pilgrimage to Makkah and the Holy Places, Saudi Arabia, which currently attracts more than two million visitors from all over the world for about two weeks. Being mobile, these MSUs can be used at many occasions without being limited to specific locations, which increases their economical feasibility and allows for higher service standards.

The concept of the system of MSUs, illustrated in fig 1, is based on an interactive response of MSUs supply for the actual demand for services at the different locations of the Mega-event. Groups of visitors, or their representatives, book on-line for their bus trips to the required locations according to their preferred venue for the event (fig 1-1). Intelligent systems [14-16] can be developed and used for a smart booking of bus trips that satisfies both needs of customers and bus operators. Accepted reservations are translated to schedules for bus trips (fig 1-2) and the control is notified. The control evaluates the shift of population from one location to another, hence the actual demand for services in every location (fig 1-3). It responds by making decisions and sending MSUs to satisfy these demands (fig 1-4). Once in place, MSUs provide the proper amount of services required by the current population at each location (fig 1-5). Such balance between demand and supply for services would satisfy both the needs of customer for adequate services and the requirements of service providers for utilization of their resources and return on their investments.

Figure 1: A schematic diagram for the proposed system of MSUs

The concept is appealing and promising in general. However, it is quite costly and risky to implement or to test such a large system directly in the Mega-event of the Hajj without prior confirmation of its appropriateness. Therefore, modelling and simulation of the system of MSUs is essential to verify its validity before recommending it for the Hajj. In a previous work [17], an approach for modelling and simulation of the proposed system of MSUs using MATLAB/SIMULINK is presented and discussed. In this paper, an extended treatment of a more comprehensive approach [18] for modelling the system of MSUs, which accounts for multi services at multi locations, variable demand for services, MSUs supply of services and traffic conditions; will be described and discussed.

2 MODELLING THE MASTER PLAN

The new Master Plan for the cities of the Hajj [19] with its six main connecting Exclusive bus roads or loops is shown in fig 2(a), which is presented in a simplified graphical form to the control centre as shown in fig 2(b). Each loop has its own support area and passes through four accommodation zones at each of the four pilgrimage cities, giving a total of 6 support areas and 96 zones. Each zone accommodates 200,000 pilgrims visitors giving the total capacity of 4.8 million visitors expected by year 2025 [19]. Zones are given 3 digit numbers...
representing city, loop and zone respectively. Since the six loops of the new master plan are almost identical, with slight variations, one loop can be modelled and duplicated, with any modifications if needed, to account for the remaining five loops. Fig 2(c) shows the Simulink and MATLAB modelling for loop-1 and its four pilgrimage zones in each of the four cities where each zone is represented by a subsystem. The model is designed as subsystems that contain subsystems in hierarchical order to organize the logic of modelling and to allow for modifications. Being modular, these subsystems can be modified individually or replaced by specialized software without affecting other subsystems.

The model consists mainly of two types of subsystems (fig 2–c). The first type represents each zone of the master plan (e.g. Zone-111), where the interaction between demand and supply of services takes place and the requests for MSUs are issued. The second type is a subsystem representing the support zone (e.g. Zone-510), where movements of buses, due to the events’ programme, are evaluated and a decision making process takes place to answer the requests for MSUs from all zones.

Figure 2: (a) The new Master Plan for the cities of the Hajj, (b) The representation of the master plan in the control screen, and (c) The Simulink modelling for loop-1 of the master plan.

3 MODELLING THE EVENTS’ PROGRAMME

The main events during the Hajj that of concern to this paper are summarised in fig 3. The movements of pilgrims from one city to another during the Hajj as shown in fig 3(a and b) produces the rapid change of population at these cities as shown in fig 3(c) with some variation due to the different travel behaviours between groups [20]. The population is measured in Pilgrim Units (PU: a unit equivalent to 50 pilgrims), which is introduced to speed up simulation and to represent the average number of passengers of a large bus. Apart from the city of Makkah, the other three cities are almost uninhabited except during the Hajj. This makes the variation of population at each zone changes from zero to 4000 PU (200,000 pilgrims) and back to zero within short period of time as shown in fig 3(c) for a typical zone from each city. The population of the residents of Makkah is not shown in the curve since they have their own services and only the additional population due to arrival of visitors is considered. Events programme is translated to variation of population vs. time and saved in a data file to be called during simulation. Simulation is set to cover the period from day 7 to day 13 of the month of the Hajj where most events of the Hajj take place. The simulation step is set to 0.025 hr (1.5 minutes) giving a total of 6720 simulation steps for the 7 days period.

Figure 3: The main events of the Hajj that considered in the model

4 MODELLING DEMAND FOR SERVICES AND MSUS SUPPLY

From a survey conducted during the Hajj 2000; 44 types of services are found to be suitable to be developed as MSUs. For simplification, these types are grouped into 16 MSU-groups of similar service capacity and importance. This allows to evaluate one service-group at a time at every simulation step and all serves-groups are re-evaluated every 24 minutes. The number of units needed to serve the whole population of each zone is identified using an approach similar to that used by the master plan where space requirement is defined for each type of service [19]. The service capacity for these MSU-groups are set to be from 267 to 4000 PU that satisfy the need of 6.6% to 100% of maximum population of a zone respectively. Therefore, each MSU fulfils the need of a given population, covering all fluctuations in their demand for that service, putting in consideration that it is unlikely that the whole population of a zone will require the same service at the same time.

Inside each zone as shown in fig 4, the signal coming from the control centre at the support zone, is separated into its main signals and distributed to subsystems representing the arriving
and departing MSUs and buses. MSUs' movements are represented by a signal of \((16 \times 16)\) matrix, where each row corresponds to a particular zone and each column to a particular MSUs-group. In the simulation, the initial conditions assume 100% MSUs at Makkah.

The population of a particular zone is estimated from the total number of loaded buses that entering and leaving that zone. This is because the master plan depends mainly on large buses for transportation [19]. The number of pedestrians entering or leaving that zone can be estimated using appropriate automated techniques such as infrared counters [21] and will be added to the total population. The service capacity available at a zone can be calculated from the number of existing MSUs. The subsystem 'MSUs-In' extracts the row corresponding to that zone only, which represents all types of MSUs that just reached that zone at the current simulation step. A 'Discrete time integrator' block is used to calculate the total capacity of MSUs that entered that zone.

Finally the MSU-Request subsystem, shown in fig 4 and in detail in fig 5, issues requests to the control centre, using a specially developed fuzzy logic controller [22], for returning an existing un-needed MSU (scoring from -10 to 0) or requesting an additional one (scoring from 0 to 10) based on local service conditions inside that zone namely: the ratio of the current service status to available MSUs service capacity, the rate of change of population, and the expected future need for services.

![Diagram](image)

Figure 4: Inside a typical subsystem 'Zone'

5 CONTROLLING THE SYSTEM OF MSUs

Preliminary and backup schedules for MSUs can be produced in advance using an appropriate scheduling technique. However, due to the dynamic nature of the Hajj, the patterns of movements of visitors are continuously changing, hence the demands for services are likely not to match forecasting, which necessitates updating the schedule frequently to reflect these changes. Therefore, fixed schedules for MSUs may not be the best alternative to achieve the objectives of higher MSUs utilization and higher customer satisfaction. On the other hand, the concept of Just-In-Time (JIT) is widely used in modern industry [23-25] and used successfully to provide supplies at the right time to the right place just before they are needed, which reduce the cost of inventory, save storage space and better match variable market demand.

Therefore, in order to respond to the variable demand for services and to reduce the total number of MSUs and increase their profitability without noticeable reduction in service supply; the concept of JIT, is applied for the system of MSUs, with some modifications, in order to send the right MSU to the right zone (location) at the right time just before it is actually needed. This can be achieved by online orders to relevant MSUs to execute next serving jobs only. Enough time will be given for preparations and transportation of MSUs. Operators can access the latest updated suggested schedule for the remaining jobs for their units just for their own convenience and as a backup-schedules. The availability of different communication technologies allows for an efficient online orders to MSUs operators to start new serving jobs just-in-time. Moreover, intelligent Fuzzy logic controllers and systems (FLC), which are used successfully in industry for controlling plant [26-29] and to evaluate service quality [30], can be developed and used for assisting decisions making for managing these MSUs.

The control centre at the support area has six main subsystems as shown in fig 6. The 'Event Programmes' subsystem represents the events of the Hajj and produces the variation of population at the different zones as described before. These data are feed to two subsystems.
that generate orders to buses to transport pilgrims to and from zones. The subsystem 'Traffic volume' calculates the traffic volume due to the movements of buses and MSUs at every simulation step. The subsystem 'MSUs Availability' evaluates the remaining MSUs available at the support zone. A transport delay block is used to represent the time needed for transporting MSUs from one zone to another.

Figure 6: Inside the subsystem 'Support zone'

The subsystem 'MSUs Movements', shown as a subsystem in fig 6 and in detail in fig 7, represents the core of modelling and decision making for the movements of MSUs. It responds to the requests for MSUs from all zones within the loop, by making decisions and issuing orders to return unneeded MSUs and to send MSUs to needy zones. MSU-Request signals form all zones are separated and fed with other inputs of MSU availability, current traffic volume and the expected traffic volume in the foreseen future to subsystems devoted to the 16 zones of the loop, to re-evaluate these requests using specially developed FLC [22]. A specially written function sorts these re-evaluated MSUs-requests then issues orders to return and to send MSUs according to their relative importance [22]. The output of the function is a (16, 2) matrix assigning a value of 1 for sending an MSU, 0 for no action and -1 for returning or releasing an MSU. The orders to returning MSUs are pre-checked with the actual MSUs available at each zone.

Figure 7: The subsystem 'MSUs Movements'

6 MODELLING TRAFFIC CONDITIONS

Since each loop in the master plan serves particular zones in the four cities and is almost independent of other loops, it is reasonable to model traffic conditions at each loop separately. The attention is focused into the traffic volume at the main loop/road rather than the local roads inside zones, due to the severe consequences of blockage or over loading the main loop. Therefore, in order to assure smooth traffic flow, the control checks that the total traffic in the main loop should not exceeds the traffic volume capacity of 750 large vehicle (LV)/lane/hr [19] at any time, even though it could reach 815 LV/lane/hr for short periods of time [31]. The 750 LV/hr is equivalent to 75 LV for every simulation step for the four lanes per loop.

Buses are represented by a signal of [16x1] matrix, each row corresponds to a particular zone and the cell value states the number of buses going to or leaving that zone. The 'Traffic-
volume' subsystem calculates the total number of vehicles (buses and MSUs) on road at every simulation step (Fig 8). The last number of buses sent to zones stored in a 'Unit delay' block is summed by a MATLAB function 'Total-Buses'. The number of MSU-batches sent to zones is multiplied by the number of units per batch extracted from the sub-system 'MSU-Batches-size' to obtain the total number of MSUs on road. The total number of MSUs on road in the last simulation step that stored in the 'Unit delay' block is summed by the function 'Total-MSUs'. Therefore the total number of vehicles is the summation of the number of buses and MSUs.

![Diagram of Traffic Volume to zones](image)

**Figure 8: The subsystem 'Traffic-volume'

7 SIMULATION RESULTS AND DISCUSSION

The modelling of the system as a whole is made by modelling each of its main components, i.e. the master plan for the cities of the Hajj, the events programmes of the Hajj, demands for services, MSUs supply for services, MSUs availability, buses and MSUs movements and traffic conditions.

A 'Just-In-Time MSUs' is used through an online control for movements of MSUs to provide services just-in-time wherever needed which achieve higher efficiency and utilization of MSUs resources. The concept is based on distributing the computational effort to subsystems, representing the different zones, so that each zone do calculation for itself and sends the final result 'MSU-request' to the control centre on the support area of that loop, which it receives requests from all zones and makes decisions for sending or returning MSUs to zones. This approach makes the logic of the model more understandable and easier to develop, reflects the real graphical distribution, and distributes computational power among zones. In reality, it also reduces the effect of the failure of any sub-system to the whole system.

Figure 9 shows the response of the system using this model to the demand for services of two MSUs groups. Group-16 shown in Fig 9(a) are of medium service capacity of 1000 PU, i.e.

25% of the population. Therefore four batches of this group fulfills the needs for the whole population of a zone. It can be seen from Fig 9(a) that the demand for this service is fairly matched by MSU supply for service, putting in consideration that existing MSUs can operate over their maximum service capacity for short periods of time to cover any shortage of services. Due to the high discrete value of the capacity of this group, some compromises are made as shown at points (1, 2 and 3) by accepting slight over and under supply of services.

On the other hand, MSU group-3, shown in Fig 9(b), is of very low service capacity of 444 PU, i.e. one batch serves only 11% of the population and 9 batches are needed to serve the whole population of a zone. Although the increased number of batches gives the control higher flexibility to better match the demand curves as seen at points (4) and (5); the large number of their units restricts transporting them during traffic peaks which causes severe shortage of services in some incidents as shown at point (6), which suggests using higher capacity MSUs to reduce their number of units.

Simulation results show that no additional MSUs will be needed. This is a significant reduction in the total capacity of services needed for the four cities from 400% of the number of visitors in the case of using fixed service centres (repeated 4 times in the four cities) to only 100% of the number of visitors by using the proposed system of MSUs.

![Simulation result for demand and supply for services typical zones in the four cities](image)

**Figure 9: Simulation result for demand and supply for services at typical zones in the four cities (a) for MSUs service group-16 and (b) for MSUs service group-3.

Simulation results also show that the additional traffic due to the movement of MSUs can be controlled and limited to less than the maximum road capacity of 750 Large Vehicles/hr/lane (75 LV/simulation step) on the main loop. The control always give priority to bus traffic to prevent any delay of the movement of pilgrims and only the excess road capacity is used to move essential MSUs. Figure 10(a) shows that if no control is applied; traffic volume will
exceed the limit in many occasions, while Figure 10(b) show the success of the control to limit the total traffic volume to less than the maximum limit at all times, which assures that traffic will run smoothly without traffic jams or overflows.

8 CONCLUSION

This paper has presented an approach for modelling and simulation of a very large system of a master plan for four pilgrimage cities and a proposed system of Mobile Service Units to serve the expected 4.8 million visitors by year 2025. The modelling of the whole system is made by modelling each of it’s main components and an online control of the orders to move MSUs is used to provide just-in-time services wherever needed.

Simulation results show that the proposed system of MSUs can be used successfully for the Mega-event of the Hajj and will not affect the programmes for transporting pilgrims by making use of the unused capacity of the road networks. Simulation results also show that a significant reduction in resources, compared with fixed services, is achieved using the proposed MSUs.

The system of MSUs is expected to contribute in achieving customer satisfaction by providing adequate amount of services whenever and wherever needed by and enabling service providers to provide higher service quality at better price.

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