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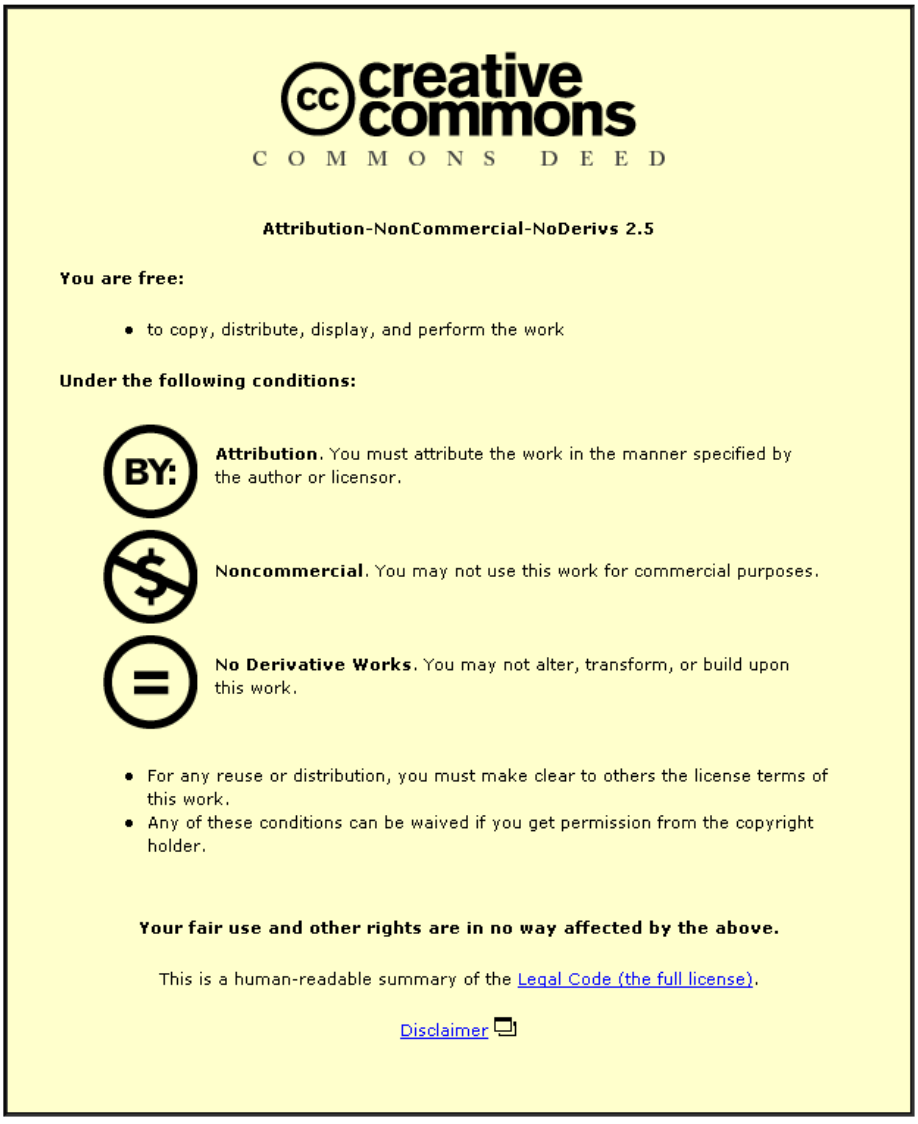

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Modelling and simulation of a system of mobile service units for the large-scale event industry

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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 in 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 event 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. Simulation results also show that a significant reduction in resources, compared with the fixed service centres currently in operation, can be achieved using the proposed MSUs.

Keywords: mobile service units (MSUs), modelling, simulation, transportation system, large-scale event industry

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 a great impact on the hosting countries and cities [**1–5**] and necessitates a 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 the 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 is costly and time consuming, while 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 for many events without being limited to specific locations, which increases their economical feasibility and allows for higher service standards. MSUs could provide pilgrims with a wide range of services such as security, first aid, health care, food and drink, groceries, toilets, public enquiries, communications, information, and administrative services.

The concept of the system of MSUs, illustrated in Fig. 1, is based on an interactive response of the supply of MSUs for the actual demand for services at the different locations of the mega-scale 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(a)). Intelligent systems [**14–16**] can be developed and used for a smart booking of bus trips that satisfies the needs of customers and bus operators. Accepted reservations are translated to schedules for bus trips (Fig. 1(b)) and the control is notified. The control evaluates the shift in population from one location to another and hence the actual demand for services in every location (Fig. 1(c)). It responds by making decisions and sending MSUs to satisfy these demands

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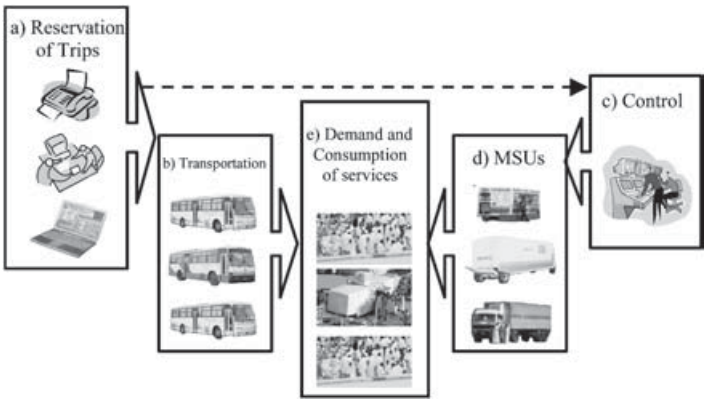

Fig. 1 A schematic diagram for the proposed system of MSUs

(Fig. 1(d)). Once in place, MSUs provide the proper amount of services required by the current population at each location (Fig. 1(e)). Such balances between the demand and supply for services would satisfy the needs of customers for adequate services and the requirements of service providers for utilization of their resources and return on their investments.

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-scale event of the Hajj without prior confirmation of its appropriateness. Therefore, modelling and simulation of the system of MSUs is essential in order 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 multiservices at multilocations, a variable demand for services, and the supply by MSUs 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 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 six support areas and 96 zones. Each zone accommodates 200 000 pilgrims/visitors, giving a total capacity of 4.8 million visitors expected by the year 2025 [**19**]. Zones are given three-digit numbers representing

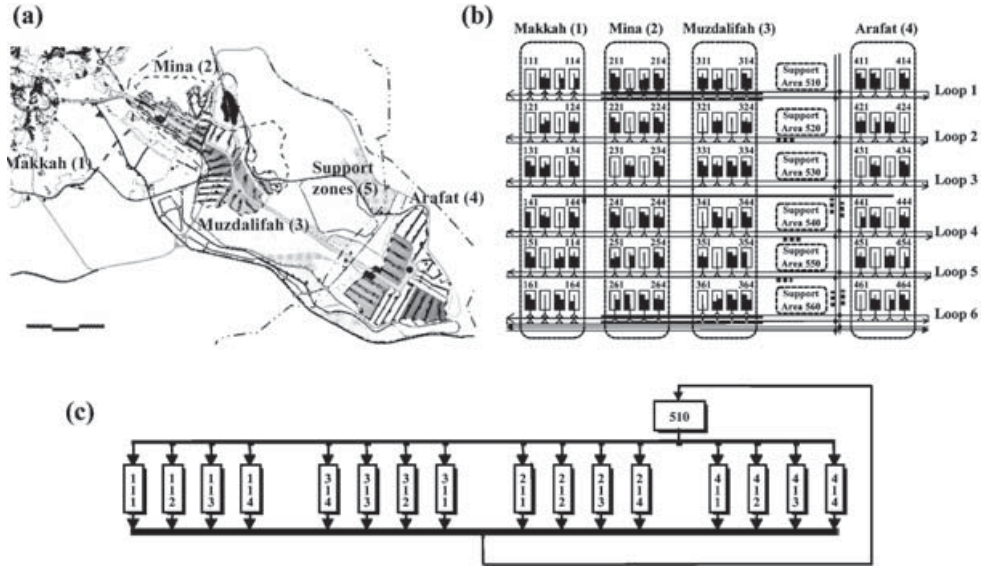

Fig. 2 (a) The new master plan for the cities of the Hajj, (b) the representation of the master plan in the control screen, and (c) the Simulink modelling for loop 1 of the master plan

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. Figure 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 more subsystems in hierarchical order, which organize the logic of modelling and 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 the 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 event programme, are evaluated and a decision-making process takes place in order to answer the requests for MSUs from all zones.

3 MODELLING THE EVENT PROGRAM

The main events during the Hajj that are of concern to this paper are summarized in Fig. 3. The movements of pilgrims from one city to another during the Hajj, as shown in Figs 3(a) and (b) produce the rapid change of population at these cities 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 on 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 change from zero to 4000 PU (200 000 pilgrims) and back to zero within a 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 on the curve since they have their own services and only the additional population due to the arrival of visitors is considered. Event programmes are translated to variations of population versus time and are 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 h (1.5 min), giving a total of 6720 simulation steps for the 7 day period.

4 MODELLING DEMAND FOR SERVICES AND MSUs SUPPLY

From a survey conducted during the Hajj 2000, 44 types of service were 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 one service group to be evaluated at a time for every simulation step and all service groups are re-evaluated every 24 min. 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 the space requirement is defined for each type of service [**19**]. The service capacity for these MSU groups are set to be from 13.4k to 200k inhabitants

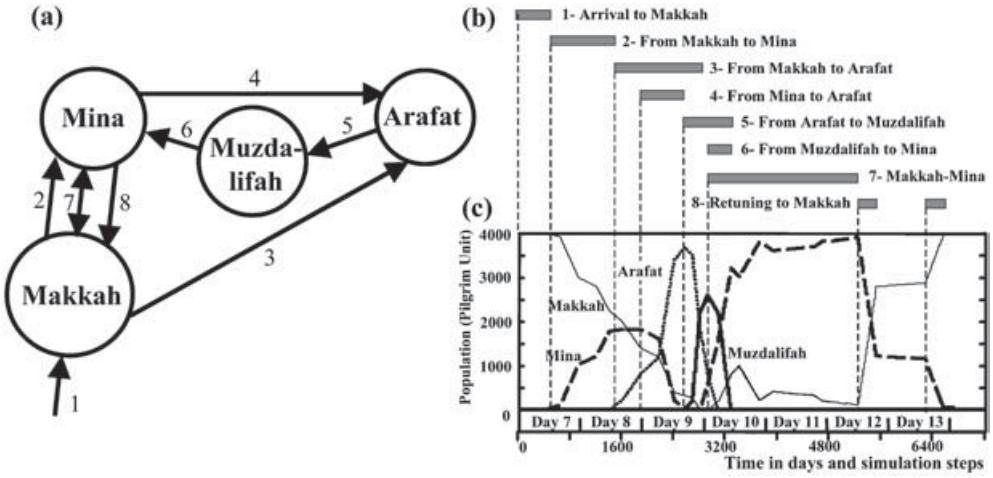

Fig. 3 The main events of the Hajj considered in the model

(267 to 4000 PU), which satisfies the need of 6.6–100 per cent of the 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, while consideration is taken of the fact 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 arrival and departure of MSUs and buses. Movements of the MSUs are represented by a signal of a 16×16 matrix, where each row corresponds to a particular zone and each column to a particular MSU group. In the simulation, the initial conditions assume there are 100 per cent MSUs at Makkah.

The population of a particular zone is estimated from the total number of loaded buses that enter and leave 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 an appropriate automated technique 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 have just reached that zone in 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

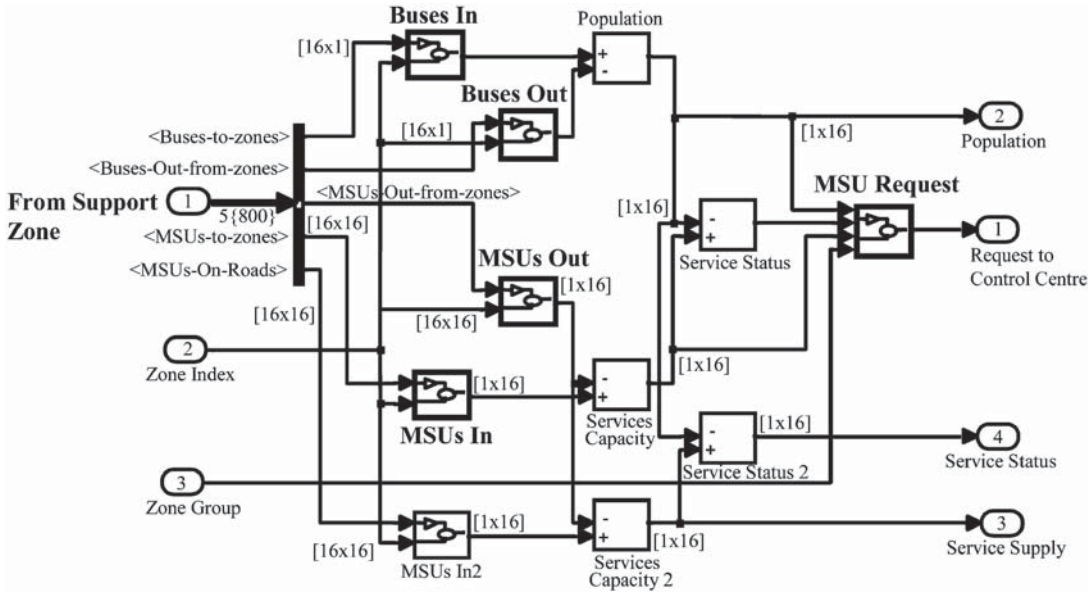

Fig. 4 Inside a typical subsystem 'zone'

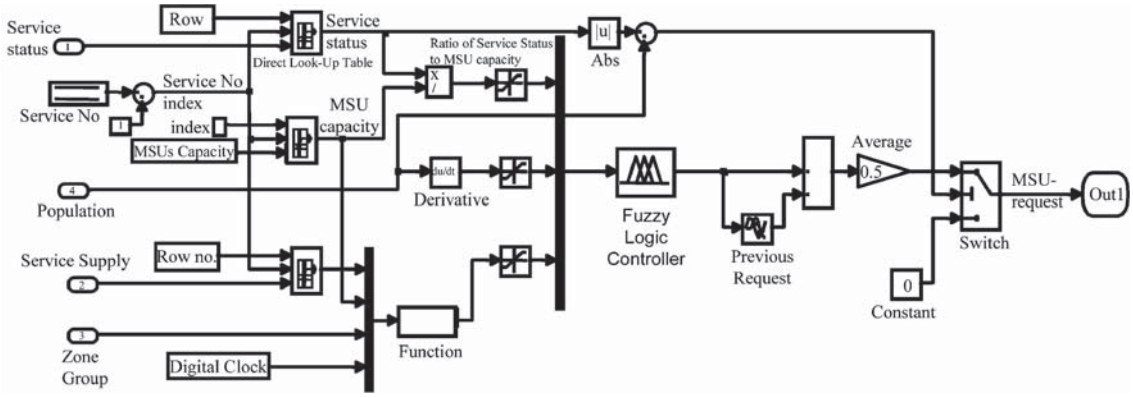

Fig. 5 The subsystem 'MSUs-Request'

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.

5 CONTROLLING THE SYSTEM OF MSUs

Preliminary and back-up 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 is successful in providing supplies at the right time to the right place just before they are needed, which reduces the cost of inventory, saves storage space, and better matches 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 a noticeable reduction in service supply, the concept of JIT is applied to 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 on-line orders to relevant MSUs in order to execute next serving jobs only. Enough time should be given for preparation 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 back-up schedules. The availability of different communication technologies allows for efficient on-line orders to be passed to MSUs operators to start new serving jobs JIT. Moreover, intelligent fuzzy logic controllers (FLCs) and systems, which are used successfully in industry to control plant [**26–29**] and to evaluate service quality [**30**], can be developed and used for assisting in decision making for managing these MSUs.

The control centre at the support area has six main subsystems, as shown in Fig. 6. The 'Event Program' subsystem represents the events of the Hajj and produces the variation of population at the different zones, as described previously. These data are fed to two subsystems that generate orders for 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 'MSU-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 and the set-up time for MSUs.

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 from all zones are separated and fed with other inputs of MSU availability, current traffic

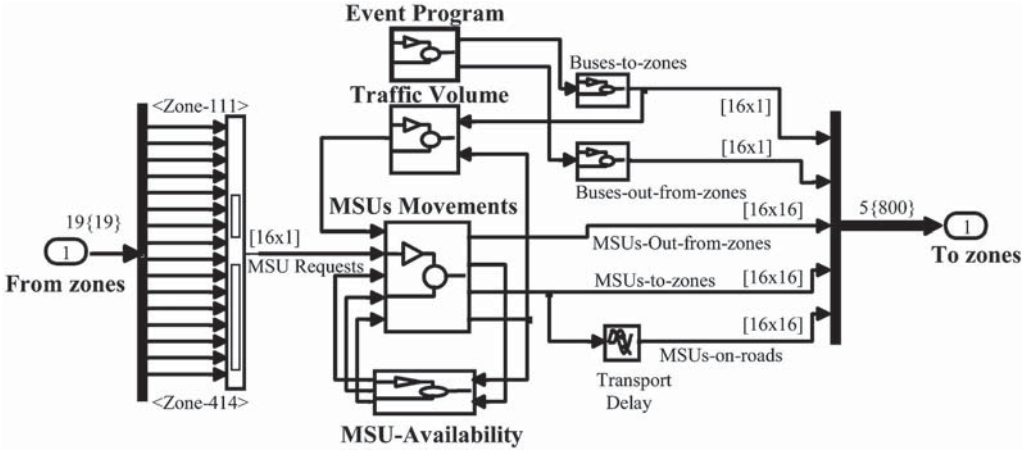

Fig. 6 Inside the subsystem 'Support zone'

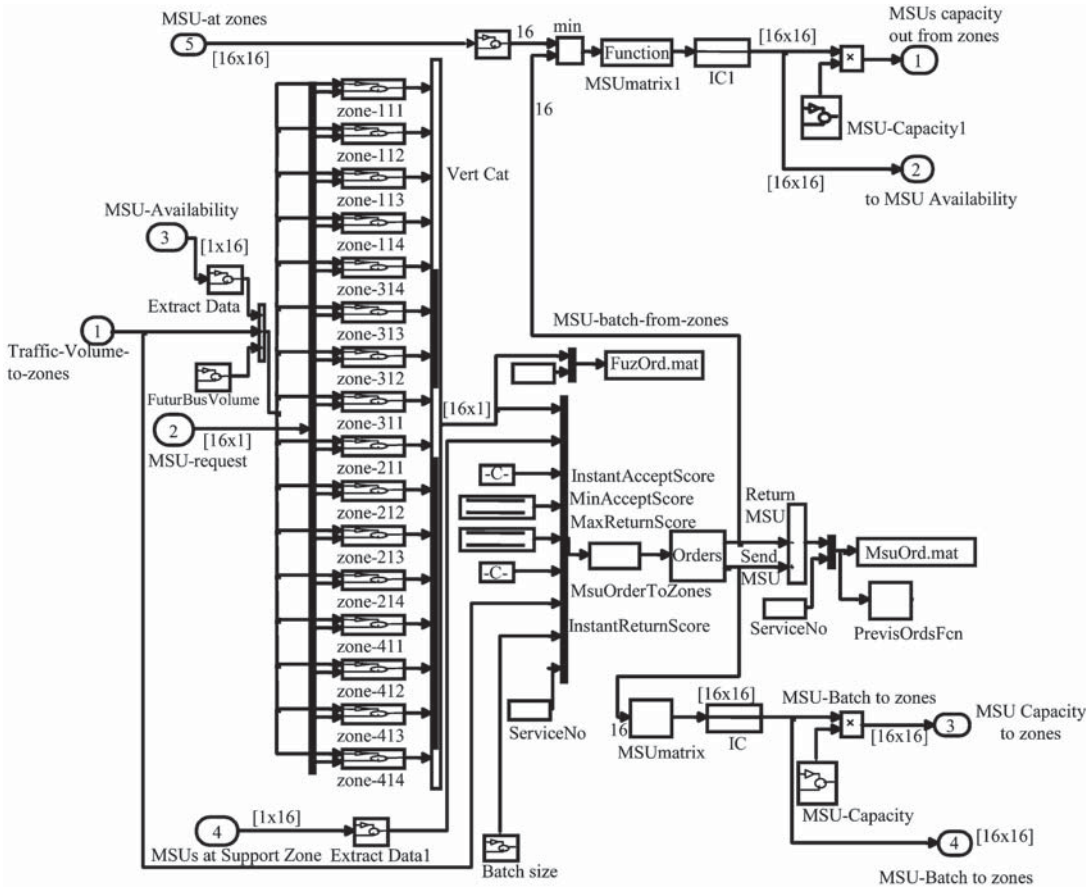

Fig. 7 The subsystem 'MSUs Movements'

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 FLCs [**22**]. A specially written function sorts these re-evaluated MSU-Requests and 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.

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. Attention is focused on the traffic volume at the main loop/road rather than the local roads inside zones, due to the severe consequences of blockage or overloading the main loop. Therefore, in order to ensure a smooth traffic flow the control checks that the total traffic in the main loop does not exceed the traffic volume capacity of 750 large vehicles (LVs)/h per lane [**19**] at any time, even though it would be possible to reach 815 LVs/h per lane for short periods of time [**31**]. The 750 LVs/h is equivalent to 75 LVs for every simulation step for the four lanes per loop.

Buses are represented by a signal with a 16×1 matrix, each row corresponding to a particular zone; 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 the 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 the 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 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.

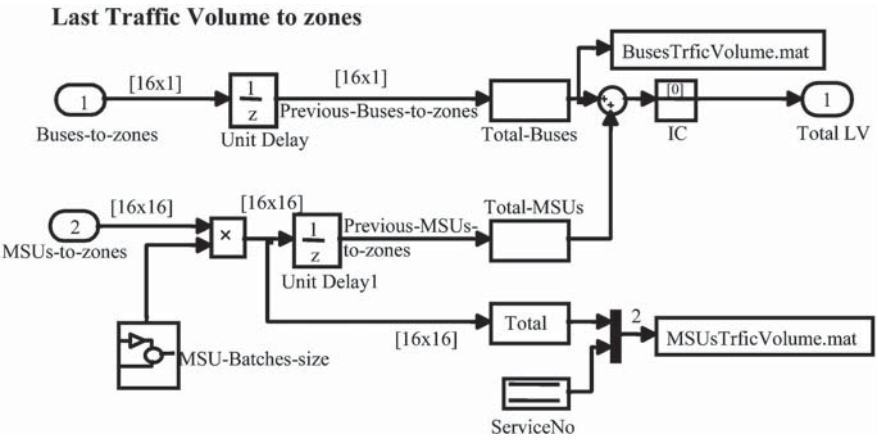

Fig. 8 The subsystem 'Traffic Volume'

7 SIMULATION RESULTS AND DISCUSSION

Modelling of the system as a whole is performed by modelling each of its main components, i.e. the master plan for the cities of the Hajj, the event programmes of the Hajj, demands for services, MSUs supply for services, MSUs availability, movements of buses and MSUs, and traffic conditions. A just-in-time MSU is used through an on-line control for movements of MSUs to provide services just-in-time wherever needed, thus achieving 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 performs calculations for itself and sends the final result 'MSUs-Request' to the control centre on the support area of that loop, which 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 geographical distribution, and distributes computational power among zones. In reality, it also reduces the effect of the failure of any subsystem to the whole system by allowing for manual procedures and direct communication with the control centre for requesting MSUs. Figure 9 shows the response of the system using this model to the demand for services of four MSU groups of various service capacities, namely group 1, group 16, group 3, and group 10. More MSU groups of various service capacities were discussed in detail and verified by simulation in reference [**22**].

Service group 1, shown in Fig. 9(a), is of a high service capacity of 100k inhabitants, i.e. 50 per cent of the population of a zone. Therefore only two batches of this group fulfil the needs of the whole population of a zone. It can be seen from the figure that the demand for service group 1 in the four zones is satisfied. However, an extra 100 per cent MSUs of this group is needed for an acceptable service level, which causes an oversupply of the services on many occasions.

Group 16, shown in Fig. 9(b), is of a medium service capacity of 50k inhabitants, i.e. 25 per cent of the population of a zone. Therefore four batches of this group fulfil the needs of the whole population of a zone. It can be seen from Fig. 9(b) that the demand for this service is fairly matched by the supply of MSUs for service. Some compromises are made, as shown at points 1, 2, and 3, by accepting slight over- and undersupplies of services. Existing MSUs should operate above their service capacity for short periods of time in order to cover these slight shortages of services, and customers usually accept that the wait to be served will be a little longer during peak times. Alternatively, additional back-up MSUs should solve such problems.

On the other hand, MSU group 3 and group 10, shown in Figs 9(c) and (d), are of very low service capacity of 22.2k and 16.7k inhabitants respectively; i.e. 9 batches of group 3 and 12 batches of group 10 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 better, as seen at points 4 and 5, the large number of units restricts their transportation during traffic peaks, which causes a severe shortage of services in some incidents, as shown at point 6. This suggests using higher capacity MSUs to reduce the number of units.

The simulation results shown here and in reference [**22**] show that no additional MSUs will be needed if medium and small service capacity MSUs are used. This is a significant reduction in the total capacity of services needed for the four cities from 400 per cent of the number of visitors in the case of using fixed

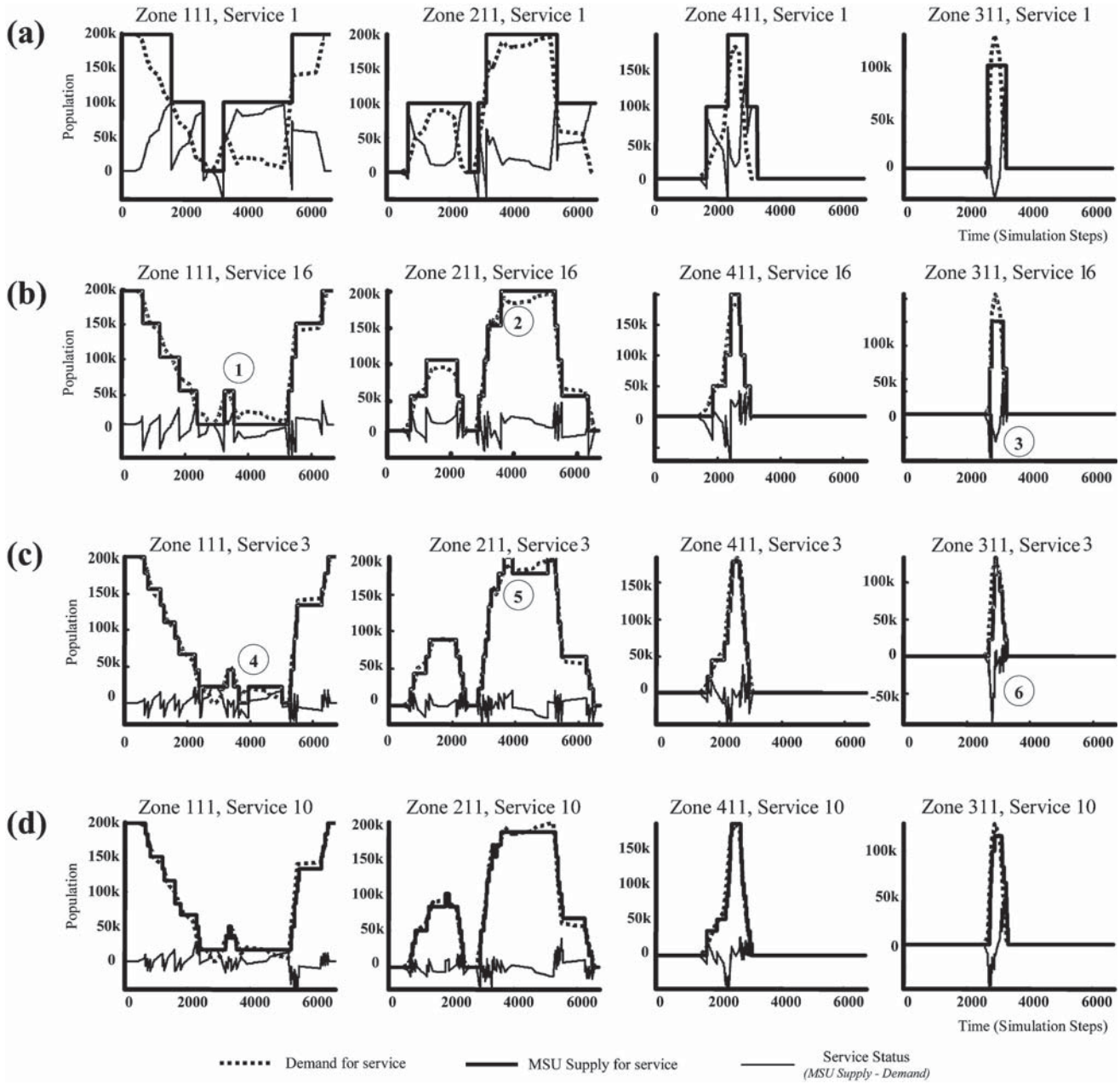

Fig. 9 Simulation results of the demand and supply of services of various capacities at typical zones in the four cities: (a) for MSUs service group 1, (b) for MSUs service group 16, (c) for MSUs service group 3, and (d) for MSUs service group 10

service centres (repeated four times in the four cities) to only 100 per cent of the number of visitors by using the proposed system of MSUs. However, an additional 10 per cent of MSUs is recommended during operation as back-up for urgent requests to relieve tight schedules and to prevent periods of undersupply of services, which in total achieves better customer satisfaction.

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 LVs/h per lane (75 LVs per simulation step) on the main loop. The control always gives 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 Fig. 10(b) shows the success of the control to limit the total traffic volume to less than the maximum limit at all times, which ensures that the traffic will run smoothly without traffic jams or overflows.

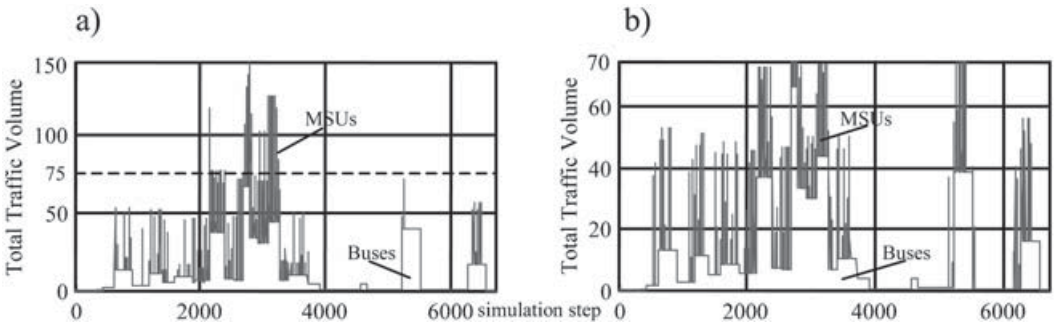

Fig. 10 Traffic volume in the main loop, (a) without control and (b) with control

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 the year 2025. Modelling the whole system is made by modelling its main components and an on-line 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-scale event of the Hajj and will not affect the programs designed 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 an adequate amount of services whenever and wherever needed and by enabling service providers to provide higher service quality at a better price.

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