Transportation Evacuation Strategies based on Vehicular Disaster Management System in Urban Network Environment

Zubaida Abd Al-Hameed Slaiby Al-Azawi

School of Computing, Science and Engineering
Salford University
Manchester, UK

Submitted in Partial Fulfillment of the Requirements of the Degree of Doctor of Philosophy

2014

Table of Contents

List of Tables

List of Figures

Acknowledgements

First, my Lord ALLAH the Most Gracious, the Most Merciful thanks and praise is all to you, without your blessing nothing would have been done about this research.

I would like to express my sincere appreciation to my supervisor Dr. Omar Alani for his support and guidance during the study. I thank him for generously sharing his good advice.

I would like to acknowledge Prof. Rashid Mehmood who supervised my PhD work from July 2010 to December 2012. The work developed under the supervision of Prof. Mehmood forms the basis of my PhD.

I would thank my co-supervisor Dr. Saad Yousif. I am also thankful to Dr. Mohamed Abdaljabar, Dr. Saleh Altowaijri and Dr. Anna Maria Vegni for the collaborative work which resulted in a number of publications (see Declaration). Parts of this thesis are taken from these papers.

I really thank Mr. Pete Skyes, the former director of the S-Paramics software division of SIAS, for his valuable cooperative, his wise comments and advices are greatly contributed to this work.

This research would not have been possible without continuous encouragement of my husband (Dr. Hamid Majid), thanks for his endless support and for being with me through the good times and the hard times. I am lucky to have my three children with me, Alameen, Almamoon and Amna. My heart felt gratitude going to my parents for their continuous love, support and prayers. I would like to say thanks to my lovely sister and kind brothers.

I am really grateful to all the members of the Iraqi Cultural Attaché in London who stood behind me through this journey.

I would like to thank all members of the School of Computer Science and Engineering. I thank the University of Salford for providing a great environment for my study. Finally, I would like to thank everybody who was important to the successful realization of thesis, as well as expressing my apology that I could not mention personally one by one.

Declaration

This PhD research has resulted into the following 5 peer reviewed International Conference papers including some papers that are invited. Other 5 papers and 4 posters are presented in different conferences. Also, a journal paper is submitted:

1. Alazawi, Z., Abdljabar, M. B., Altowaijri, S., and R. Mehmood, "Intelligent Disaster Management System Based on Cloud-Enabled Vehicular Networks," Proceedings of the 11th International Conference on ITS Telecommunications (ITST), Petersburg, Russia. IEEE, pp. 361-368, 2011.

2. Alazawi, Z., Abdljabar, M. B., Altowaijri, S., Vegni, A. M., and R. Mehmood, "ICDMS: An Intelligent Cloud Based Disaster Management System for Vehicular Networks," Proceedings of the 4th International Conference on Communication Technologies for Vehicles, Nets4Cars/Nets4Trains, Lithuania, Germany. Springer-Lecture Notes in Computer Science, vol. 7266, pp. 40-56, 2012.

3. Alazawi, Z., Alani, O., Abdljabar, M. B., and R. Mehmood, "An Intelligent Disaster Management System Based Evacuation Strategies," Proceedings of the 9th International Symposium on Communication Systems, Networks Digital Signal Processing (CSNDSP), Manchester, United Kingdom. IEEE, pp. 673-678, 2014.

4. Alazawi, Z., Alani, O., Abdljabar, M. B., and R. Mehmood, "Transportation Evacuation Strategies Based on VANET Disaster Management System," Proceedings of the 4th International Conference on Building Resilience, Manchester, United Kingdom. Elsevier's Economics and Finance Procedia, vol. 18, pp. 352-360, 2014.

5. Alazawi, Z., Alani, O., Abdljabar, M. B., Altowaijri, S. and R. Mehmood, "A Smart Disaster Management System for Future Cities," Proceedings of the ACM International Workshop on Wireless and Mobile Technologies for Smart Cities, Philadelphia, USA. ACM Press, pp. 1-10, 2014.

6. Alazawi, Z., Alani, O., Abdljabar, M. B., and R. Mehmood, "Average Vehicle Occupancy Contribution Evaluation in Vehicular Disaster Management System," Proceddings of the 15th Annual Postgraduate Symposium on the Convergence of Telecommunications, Networking and Broadcasting (PGNET). Liverpool, United Kingdom, 2014.

7. Alazawi, Z., Alani, O., Abdljabar, M. B., and R. Mehmood, "State-of-the-Art Technologies based Disaster Management System," Submitted to International Journal of Disaster Resilience in the Built Environment (IJDRBE).

8. Alazawi, Z. and Mehmood, R., "Intelligent Transportation Systems: Design & Evaluation," Poster and Abstract, Published and Presented in the 1st Iraqi Conference on Engineering Science. London, United Kingdom, 2011.

9. Alazawi, Z. and Mehmood, R., " ¿ Transport, Design & Evaluation," Poster and Abstract, Presented at the School of Engineering, University of Swansea, Swansea, United Kingdom, 2011.

10. Alazawi, Z., "An Intelligent Transportation Disaster Management System," Presented in the Proceedings of the Postgraduate Annual Research Conference (SPARC), University of Salford, Manchester, United Kingdom, 2012.

    This paper was selected as the best paper in the conference and was published in the proceeding of the conference

11. Alazawi, Z., "An Intelligent Disaster Management System with Cloud Computing and Vehicular Network," Presented in the Proceedings of the 3rd CSE Doctoral School Postgraduate Research, University of Salford, Manchester, United Kingdom, 2012.

12. Alazawi, Z., "An Intelligent Disaster Management System with Vehicular Networks," Presented in the Proceedings of the Postgraduate Annual Research Conference (SPARC2013), University of Salford, Manchester, United Kingdom, 2013.

13. Alazawi, Z., " ¿ Disaster Management System For Evacuation Techniques," Presented in Proceedings of the 3rd CSE Doctoral School Postgraduate Research, University of Salford, Manchester, United Kingdom, 2013.

14. Alazawi, Z. Alani, O. and Yousif, S., "An Intelligent Disaster Management System with Cloud Computing and Vehicular Networks," Poster and Abstract. Presented in the Dean's Annual Research Showcase, University of Salford, Manchester, United Kingdom, 2013.

15. Alazawi, Z. Alani, O. and Yousif, S., "Transportation Evacuation Strategies based on Vehicular Disaster Management System," Poster and Abstract. Presented in the Dean's Annual Research Showcase, University of Salford, Manchester, United Kingdom, 2014.

Dedication

To God, who is indeed the Beneficent and the Merciful

To my parents as it is their dream, which I fulfilled

To my husband, who has supported me in all endeavours

To my children who make the life fun

Abstract

The importance of emergency response systems have grown tremendously in the recent times due to the many manmade and natural disasters in recent years such as September 2001, July 2005 London bombings and the 2011 Japan earthquake and tsunami disaster. Disasters cost huge human, social and financial losses. For example, in Typhoon Haiyan, as of November 2013, the official death toll from Philippines's devastating storm has passed 10,000 people. In addition, based on early estimates, the reconstruction costs could come to as much as $20bn (£12.3bn). Conventional methods for disaster management have shown little prospects of realizing the true potential of current and emerging technologies.

This PhD research aims to propose and evaluate a disaster management system based on the emerging ICT technologies with a focus on transportation in urban environments. This work is presented on an Intelligent Disaster Management System based on Vehicular Ad hoc Networks (VANETs) and Cloud Computing. Our research objective is to increase the safety and system efficiency, to reduce the accidents, congestion, and manage the emergencies and disasters. The effectiveness of the intelligent system has been demonstrated through modelling the impact of disaster on real city transport environments and compares it with the case where the intelligent proposed system was in place, and ability of generalizing the concept was increased through applying the proposed system on different cities. By applying our system, substantial benefits have been achieved in terms of improved and balanced traffic flow and smooth evacuation rates.

Furthermore, a micro-simulation software model has been developed which employs the vehicular disaster management system in order to investigate the transportation evacuation strategies potential in reducing the human and economic losses.

The particular contribution of my thesis is in the modelling and simulation of the traffic for disaster and evacuation scenarios. To this end, this project uses a range and mix of modelling and simulation technologies including macroscopic and microscopic simulation models; OmniTRANS and S-Paramics transport planning software.

During the course of this PhD, disaster scenarios of varying scales involving 2-3 different cities of various sizes and characteristics have been modelled and analysed, thereby presenting a system which deliver advanced services in managing disasters which results in lower losses.

Also, the Average Vehicle Occupancy impact on the evacuation process time has been investigated. Literally, it represents the higher number of car occupancy which means less number of trips required to the evacuation process. The results have shown that AVO contributes effectively in evacuation plans that are in place.

Additionally, two different evacuation strategies have been applied and evaluated simultaneously and isolated. Subsequently, either continues the processes or perhaps there is a need to change the strategy where applicable and appropriate. In other words, after propagating the evacuation strategy, the traffic situation has been assessed and observed the effectiveness of the disaster management system on the network by comparing the performance of the proposed system against the traditional system. To sum up, the comparison between both scenarios shows the ability to secure more of vehicles, up to double the number, and hence improve the network performance in terms of safety. Moreover, there is an improvement in flow rate of many critical links. Many blocked links are turned into some reds and blues which means an improvement seemed to occur to the whole network.

INTRODUCTION

Information and Communication Technologies (ICT) are continuing to make a profound impact on the way we live and work, enabling our move towards a Digital Economy (DE). A Digital Economy aims to enable sustainable replacements and organizations of the various socio-economic interactions and activities that we undertake, using technologies such as Internet, mobile phones, sensors and social networks. Digital technologies offer huge potential for providing efficient and easy access to public services. They can connect people in rural areas, enable remote access to healthcare, build social inclusion, and help solve our energy crisis. For example, many governments have described clearly just how vital the ICT infrastructure, such as in the UK it has been estimated that it contributes £102 billion in gross value-added, and employs over 2.5 million people [1].

Intelligent Transportation Systems are set to play critical roles in responding to emergencies and large-scale disasters. Transportation is an important dimension of this move towards a Digital Economy. It is a major public and government concern impacting on almost every aspect of our daily life. According to the most frequently cited figures, produced by the Confederation of British Industry (CBI) early this century, congestion costs the UK £20 billion annually [2]. This figure should have reached £30 billion by 2010, and is set to rise to £32 billion by 2025 [3]. Also, it is predicted in the survey conducted by the Department of Transport in the UK that by 2015, total traffic on the roads will grow by over 30 present compared to the traffic in the year 2000 [4].

Next generation economies will rely on Intelligent Transportation Systems (ITS), enabled through increased ICT penetration. The objective is to increase safety and system efficiency, reduce accidents, congestion and journey times, improve its carbon footprint and manage emergencies and disasters.

It has been noticed that most people could be unaware about the upcoming disasters and this lack of concentration would increase the losses and damage during and after the disasters. Accordingly, adequate and advance disaster warnings, effective and updated policy including

different dimensions can reduce the human losses and economic damage, especially in countries prone frequent disasters [5].

1.1   Problem statement

The importance of disaster and emergency management systems cannot be overemphasized today due to the many manmade and natural disasters in the recent years such as September 2001 attacks, the July 2005 London Bombings and the 2011 Japan Earthquake and Tsunami disasters. The overall cost of the Japan disaster alone is estimated to have exceeded 300 billion USD. The conventional methods for disaster management have shown little prospect of realizing the true potential of current and emerging technologies. This has driven many new initiatives and programs for emergency response and evacuation initiatives in countries throughout the world, in particular in the USA, Europe, Japan and China. See, for example [6], [7], [8], [9] and [10]. In the USA, also, a great deal of advisory and policy documents have been developed by various government authorities through surveys, consultations, experiences and other means of research: see e.g. [11], [12], [13] and [14].

Meanwhile, one important dimension that shows significant impacts and should be taken into account during the disasters is the transportation network ability to adapt the increase in demand and the random driver behaviours. Most of the transportation network capacity design lags behind the residential requirements especially in urban networks. The designers and planners start to identify that many transport links are not adequate to serve the elevated travel demand during and after the disasters, particularly the urban networks.

Unprecedented advancements in information and communication technologies over the last few decades have increased the ability to monitor and manage transportation system in real-time and at high granularity. In contrast, insufficient information with regard to sources and information available makes the mission of controlling and guiding people too difficult. The communication has an important role to play, while studies show increased losses in such events. The interested researchers and practitioners are stressing the importance of considering new ways of developing disaster management systems.

Now, thesis problem could be summarized by the following:

Would a new proposed evacuation strategies based on vehicular disaster management system contribute to a lower losses and transportation dead logs?

1.2   Aims, objectives and contributions

This research aims to propose and evaluate a disaster management system based on the emerging ICT technologies with a focus on transportation in urban environments. To this end, this research presents our work on an intelligent disaster management system based on state-of-the-art technologies including Vehicular Ad hoc Networks (VANETs) and Cloud Computing, see [15].

The system is intelligently able to gather information from multiple sources including from the point of incident and make effective strategies and decisions, and propagate the information to vehicles and nodes in real-time. A demonstration of the effectiveness of our system has been done through modelling the impact of disaster on different real city transport environments and compares it with the case scenario where our system was in place. Substantial benefits in terms of improved and balanced traffic flow and smooth evacuation are achieved.

The particular contribution of my thesis is in modelling and simulation of road traffic for disaster and evacuation scenarios. I have used a range and mix of modelling and simulation technologies including the commercially available OmniTRANS transport planning software and S-Paramics ITS System simulation software. During the course of this PhD thesis, the aim is to model and analyse disaster scenarios of varying scales involving different cities of various sizes and characteristics. These analyses carried out over a range of cities and scenarios have fed into establishing suitable methodology and programme which are capable of bringing innovations in the disaster management area as well as in the broader transportation area.

1.3   Research methodology

The following research methodology has been developed and adopted for this research project. The main stages of the methodology are as outlined below:

1. Review previous literature

   In this step, profound evaluation of the previous works has been done to the identify issues in major topics such as Intelligent Transportation System and Services (ITSS), Information and Communication Technologies (ICT) and emergency response systems. We have acquired a substantial knowledge by performing a comprehensive study from previous literature.

2. Identify and define the research problem and contribution

   It was noticed, through reviewing the literatures, how massive losses can be occurred due to disasters. To this end, the research begins by identifying how the ITS and ICT in disaster management system can be exploited in order to achieve the objectives of the research. The disaster impacts have been evaluated using various scenarios to reflect different circumstances and extract system requirements.

3. Acquire a real city data

   Data for different real cities from different sources are obtained, and we would focus on the details of the data and the extraction of the data, and hence analysing the data (in normal scenario and various disaster scenarios). Just to clarify, an agreement has been signed between Salfrod University and the city X Council to use the city X data in our project but not to mention the city name and other details.

4. The Intelligent Disaster Management System: Develop, apply and evaluate through number of scenarios

   Various scenarios and cities conditions have been conducted. We apply and evaluate our proposed Intelligent Disaster Management System influence on two real city environments, using macro-simulation model, to investigate the system's performance. The proposed system is flexible for different problem scales.

5. Develop a software model: An SNMP controller

   The proposed Intelligent Disaster Management System performance in transportation evacuation strategies has been investigated involving micro simulation software called

S-Paramics ITS system. The software model is designed to fit different transportation strategies sitting.

6. Evaluate the model design

A comparison is completed for the results of different traffic evacuation strategies. We compare the results of two different systems, a traditional disaster management system and our proposed intelligent system. The comparison is carried out for evacuation strategies scenarios as well to introduce the software design benefits.

7. Present the PhD thesis

In this final stage, the complete PhD thesis will be presented.

1.4   Thesis organization

The thesis is organized as follows:

- **Chapter 2** defines the fundamental concepts relevant to this thesis. These include Digital Economy, Intelligent Transportation Systems (ITS), and Cloud computing. Also, various ITS system examples have been applied in different researches and practices, including disaster management systems, are presented.

- **Chapter 3** provides the literature review relevant to this thesis including VANETs, disaster management systems, communication applied at different disaster management systems, and evacuation types and models.

- **Chapter 4** provides introduction to the modelling and simulation methods that have been used to model disaster and evacuation scenarios. We are using a range of techniques to model different disaster and evacuation scenarios including a tool based on OmniTRANS and S-Paramics software. The chapter provides a broad introduction to the area of traffic modelling covering various classes of modelling and simulation methodologies.

- **Chapter 5** gives the design and architecture of our proposed Intelligent Disaster Management System. The architecture layers are described in details. Also, the intelligent system proposed has been extended. The system model was improved by means of introducing a novel message propagation algorithm through VANETs, and the effectiveness of the system was validated by means of extended simulation results calculated in Chapter 6.

- **Chapter 6** provides the analysis and evaluation results of the Intelligent Disaster Management System for two Iraqi cities (Al-Ramadi and Al-Huseneya cities). The results are acquired using a macro-simulation model, called OmniTRANS model. The evaluation is done to measure the performance of the proposed system by comparing the results obtained with the traditional systems.

- **Chapter 7** dedicated to introduce the software model design and its usefulness. The proposed system model is improved by means of developing a programme, SNMP controller, and the effectiveness of the model was validated by means of extended simulation results in Chapter 8. Also, brief introductions about previous studies that reported having discussed some relevant are presented.

- **Chapter 8** tests and evaluates of the model benefits are conducted in this chapter to measure the performance of the proposed emergency system using the model. Different traffic evacuation strategies outcomes have been selected. A comparison has been presented between the results which obtained via using the controller to reduce the losses. This investigation and evaluation has been tested using the city X transportation information.

- Finally, **Chapter 9** concludes the thesis and evaluates the computation results, and gives direction for the future work.

Two appendices complement the chapters above as follows:

Appendix A: contains different disaster scenarios information which applied for the city X.

Appendix B: contains a comparison between the traditional disaster management system results and our intelligent disaster management system results when we apply different driver response percentage and speed limits.

BACKGROUND

This chapter provides a definition on the important elements which contribute to the topic of this PhD, i.e. Intelligent Transportation Systems and Services (ITSS), Cloud computing, disasters and emergency response system.

A brief description of digital economy (DE) is given at the start of this section. Subsequently, a definition for Intelligent Transportation Systems is provided followed by a review and discussion of its various dimensions. Also, this research presents a review of around 30 applications and services representing Intelligent Transportation Systems. An explanation of cloud computing has been provided in this chapter. Finally, a definition of disaster and emergency response system is shown at the end of this chapter.

It is worth mentioning here, Section 2.2 is mostly based on a review of some sources, particularly a review of a module entitled "An Introduction to Intelligent Transportation Systems" [16], and some additional sources were used to prepare these sections and these include [17], [18], [19], [20], [21] and [22]. Section 2.5 provides some examples on ITSS prepared using over 30 sources. Other important subjects will be explained through other chapters.

2.1   Digital Economy

A Digital Economy is "*An economy that is based on electronic goods and services produced by an electronic business and traded through electronic commerce. That is, a business with electronic production and management processes and that interacts with its partners and customers and conducts transactions through Internet and Web technologies*" [23].

Digital Economy has also been defined elsewhere as "The global network of economic and social activities that are enabled by information and communications technologies, such as the Internet, mobile and sensor networks" [24].

There are not many sources where you can find a formal definition of digital economy; however, there are many examples of products and services that exist in which represent digital economy.

2.2 Intelligent Transportation System (ITS)

Intelligent Transportation System (ITS) refers to "*Efforts to add information and communications technologies to transport infrastructure and vehicles in an effort to manage factors that typically are at odds with each other, such as vehicles, loads, and routes. The objective of ITS is to improve safety, reduce vehicle wear, transportation times and fuel consumption*" [17].

Complicated transportation systems are existed in many developed countries and it has been noticed that some difficulties can be emerged involving congestion and safety issues; in other words, wasting time and money. Therefore, government and private sectors have been urged to address the problems, and as a result decided to develop an Intelligent Transportation System (ITS). Indeed, it is a part of the governments' ongoing digital economy agenda applied to the transportation sector.

ITS has been defined in another source as "Rapidly emerging transportation products, services and systems which are based on advanced technologies such as computers, communications and electronics" [18].

ITS is characterized by information, dynamic feedback and automation that allow people and goods to move efficiently. They encompass the full scope of information technologies used in transportation. The emergence of these technologies as a new pathway for transportation is relatively new [25].

ITS comprises various technologies, applications and communication tools. Intelligent Transportation Systems vary in the technologies applied, from basic management systems such as car navigation to traffic signals, to monitor applications such as security CCTV systems. Therefore, all the information about the conditions of the current route can be supplied by the appendices of the systems which could provide applicable alternative route to solve any problems. For further information, please visit also [26], [27] and [28].

2.3 Basic concepts of ITS

Intelligent Transport System (ITS) has been defined as "A range of tools that combine modern computing and communications technologies for transport applications" [19]. Therefore, Intelligent Transportation System is the utilization of ICT (such as sensing, communications, computing and algorithms) to improve transportation systems.

This section presents the main perception regarding the Intelligent Transportation System and its relatives which have explained the significant services provided.

2.3.1 Big ITS ideas

- The ITS 4 Technologies: Such as signal control, sensors and camera control.

- The ITS Insight: Linkage of Vehicle and Infrastructure, the relation between the vehicles and the route conditions.

- The Potential of Pricing: Potential of pricing in the sense that pricing/cost may be used to improve transportation services

- Mobility: Ability to move around (to be mobile).

- Information: The ITS should contain all information needed to manage and control the systems

- Inter modalism: Different modes of transportation used in the transportation systems.

- Institutional Change: The importance of the ITS is the big issue in the system, therefore, any change is acceptable.

- Nationally-Consistent System: This program should work parallel with any local programs, so the manager can get the benefits.

- Internationally-Consistent System: Also it is better if these services can work internationally, so that the users can completely benefit from these services.

2.4 Subsystems of ITS

Intelligent Transportation Systems include a wide and growing suite of technologies and applications. ITS applications can be grouped as categories below:

2.4.1 Advanced Transportation Management Systems (ATMS)

Advanced Transportation Management System (ATMS) can be defined as "Detects traffic situations, transmits them to control centre via communication network, and then develops traffic control strategies by combing all kinds of traffic information" [29].

ATMS provides extreme information in order to improve the efficiency of the route, optimize the safety and reduce the cost of fuel. It can be done before, during and after the trip. Such as traffic signals, ramp meters, variable message signs (Dynamic Message Signs), Traffic Operations Centres (TOCs) and Adaptive Traffic Signal Control (ATSC) [30].

2.4.2 Commercial Vehicle Operation (CVO)

Commercial Vehicle Operation (CVO) is an application for trucks, and could be defined as "Applying the technology of ATMS, ATIS and AVCS in commercial vehicle operation such as trucks, buses, taxes and ambulances in order to improve efficiency and safety" [29].

The digital radio service forwards the data to the central office of the trucking company. A computer system in the central office manages the fleet in real time under the control of a team of dispatcher. The main aim of this system is to enhance and improve the efficiency and safety of commercial trucking, and reducing the emissions. Therefore, the manager is capable to control the fleet of vehicles and achieve the aims in the best way, with the least trouble.

2.4.3 Advanced Vehicle Control System (AVCS)

AVCS can be defined as "Applies advanced technologies in vehicles and roads, and helps drivers control vehicles in order to reduce accidents and improve traffic safety" [29] such as Automatic Vehicle Location (AVL) [30] and [31], further information are presented in [21].

2.4.4 Advanced Public Transportation Systems (APTS)

Advanced Public Transportation System (APTS) is "*A way for the public (all the people) to travel around, it is a way for people to travel quickly and cheaply without needing their own cars. Public transport helps many people to travel at the same time*" [16].

Public transport (also public transportation, public transit, or mass transit) has another definition; it is defined as "Public transport comprises all transport systems in which the passengers do not travel in their own vehicles. While it is generally taken to include rail and bus services, wider definitions include scheduled ferries, taxicab services etc. In other words, any system that transports members of the general public" [22].

For example, allow trains and buses to report their position so passengers can be informed of their real-time status (arrival and departure information). Further explanation and definitions have been described in [29].

2.4.5 Advanced Traveller Information Systems (ATIS)

One of the main applications of the ITS is the Advanced Traveller Information Systems (ATIS). It can be defined as "An integral component of the concept of Intelligent Transportation Systems. ATIS are envisioned to enhance personal mobility, safety and the productivity of transportation" [32].

It is an advanced package of information which is provided for the drivers to increase the driver safety and raise the efficiency of the road and eventually the transportation system. Advanced Traffic Management and Traffic Information Systems (ATMIS) have offered significant potential for avoiding and reducing traffic problems such as congestion. For example, the system is able to provide the real-time traffic information, transit routes and parking information, and finally the information about delays due to congestion, accidents, weather conditions, or road repair work [30].

Such a system has the potential to provide the feedback which could help the travellers to make the right decision about their trip, such as travel time, avoiding congestion and parking. The information have been provided pre-trip and during the trip. It is important to inform all the travellers about the most important and relevant information.

2.4.5.1   What is travel information?

Travellers can avoid the congestion along their route by being provided with the major, serious and comprehensive information about their trip. It is more useful if managers capable to give the information, which provides the best guide to help the travellers, before, and even during their trip and result in reducing the problem consequences in the future.

This information can be available between the system operators and the travellers through some means of communication.

2.4.5.2   What information do travellers want?

There are two main requirements which should be provided:

- Static: The fixed conditions about the roads or maybe some activities which have been planned previously; such as the design of the road and schedules.

- Dynamic: The information which can change at any time according to the road conditions; such as traffic conditions, real-time incidents and the weather.

2.5   Further examples of Intelligent Transportation Systems

A number of ITS examples have already been presented in Section 2.4. In the following, more than thirty examples of ITS systems will be listed. Their services and applications are mainly exploited and utilised to achieve their invention objective, and some of these examples are used in this study:

ITS	Design Function
Safety Cameras	To remind motorists not to exceed the speed limit [19]
Portable Collision Avoidance System (PCAS)	In order to provide reliable and precise traffic information. It is noted that we can deliver the information in a low rate while employing the PCAS [33]

Inductive Loop Detection	Basically, we can account how many cars used this road. In addition, it helps to measure other important road variables such as speed, length, and type of vehicles same as camera and other sensors are used [16]. Similar work has also been reported elsewhere [34]
Queue-end Warning System	It predicts queue-end location and then informs the drivers. As a result, the rear-end collisions can be avoided [35]
Automated Speed Enforcement (ASE)	Automated Speed Enforcement (ASE) systems combine radar with cameras to enforce speeding laws. A vehicle that is speeding is detected by radar, which triggers a camera to take a photograph or digitally records the license plate number, and the driver is issued a citation, usually through the mail. ASE provides a cost-effective method to improve speed enforcement and allows police officers to focus on other enforcement priorities [30]
A 98 B-Line Rapid Bus Service	This system could provide all the bus service information which might consist of the real-time of the trip, the traffic situation and all priority information are presented through this service [36]
Transit Signal Priority	This system is able to recognize the bus when it enters the junction, and then, the signal could be changed from red to green or extend time of the green signal if it is possible regarding to other traffic. This could be much affect by reducing the time for all riders [37]

In-Car Switched Ethernet Network without Prioritization	This example explains the importance of Internet Protocol (IP), which is the fundamental of the existing real time communication, especially which could be located in car network. This protocol can play a vital role as a technology transmitter that introduced between several different in-car network rules such as IEEE 802.3 Ethernet [38]
Continuous Air interface Long and Medium range (CALM)	Provides continuous communications between a vehicle and the roadside using a variety of communication media, including cellular, 5 GHz, 63 GHz and infra-red links [39]
Video in automotive safety systems	Car safety could be supporting by using video-based systems, this system is applied through high-performance media operations. These sensors could be interacted with other car parts such as engine and braking, and provide all information in order to avoid the problem or decrease the damage at least [40]
Advanced Parking Information System	Electronic signs provide information about the number of space available in some parks, the allocation of parks, and all other information which is really useful especially for new visitors [41]
Secure Automotive On-Board Protocols	It is worth noting that each vehicle contains of electronic devices which have being necessary controlling by appropriate software that has been usually updated. Therefore, a high level of secured process is requested such as on-board security architecture [42]

Real-World Measurements of Non-Line-of-Sight Reception Quality at Intersections	A task of reducing of accident is taken into account by Vehicular Dedicated Short Range Communication (DSRC). It presents cross-traffic assistance as an example to achieve the aim. DSRC suggests using a regular Cooperative Awareness Messages (CAM). Therefore, the selection was using 5.9GHz because of a high frequency it has. The result of the test was "the collected data shows that NLOS reception is possible. Reception rates stay mostly well above 50% for distances of 50 meters to intersection center with blocked LOS" [39] and [43]
Delivering Broadband Internet Access for High Speed Trains Passengers	Providing an internet access services on high speed train. These solutions are supported by an internal project, and Mobile Router in Multiple Access. Moreover, a company such as Orange contributed to maximize the efficiency of internet connectivity services by providing some technical infrastructure facilities, and further evolution of the mobile router towards ITS architecture is participated as well [44]
Towards Standardization of In-Car Sensors	In this example, to obtain homogeneity across the stakeholders, it has been suggested to use the same microchip in the vehicles. Hence, this could contribute to increase the readability of helping the operators, managers, practitioners and designers of the transportation system [45]
Fully integrated Intelligent Transportation Systems	Such as vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) integration, enable communication among assets in the transportation system, Intelligent Speed Adaptation (ISA) [30] and [31]

Train Tracking and Shadowing Estimation Based on Received Signal Strength	It is useful, it presents an alternative method especially when the GPS failure to continue with system. It is based on radio communication system through receiving signal strength (RSS) by several mobile stations placed on top of different carriages of the train [46]
Count-Down Signal	This device provides a conventional signal. The pedestrian knows the time remains to allow crossing through this signs [56]
The Media Independent Handover (MIH)	IEEE 802.21 protocol has been used in railway system to support a highly frequent, repeated and foreseeable handovers between different technologies. This protocol provides a high quality handovers among heterogeneous IEEE 802 systems and with cellular systems also. The main aim of this contribution is to build a seamless layer which can provide independence to the application layers from the radio access technology underneath. IEEE 802.11 and IEEE 802.16 are considered in this application [48]
iRide	A Cooperative Sensor and IP Multimedia Subsystem Based Architecture and Application for ITS Road Safety: A description is provided for an application that has been used to inform the vehicle drivers about any serious situation that could be appeared on their road, the application is called iRide (intelligent ride). It is based on collection of a comprehensive real data from traffic users by using sensors. Also, it could be worked when the driver is able to connect with the infrastructure sensors. The concept of this application is based on the prediction of the road dangerous conditions [55]

Direct Train to Train Propagation Channel in the 70 cm UHF-Band	Beside different operational conditions like front, rear, and flank approaches of trains, it has been investigated several topological scenarios on both, single and double track sections along the line. We will also discuss the observed characteristic changes in narrow band signal attenuation and Doppler spectra for passages through forests, hilly areas, stations and a tunnel. The outcomes of the first workshop about direct communication between railway vehicles are described in this application. The aim of this work is to determine the propagation channel in case of direct communication between railway vehicles. The investigation is towards different operational conditions like front and rear approach [57]
Wireless Protocol Design for a Cooperative Pedestrian Protection System	It is based on using a set of sensor technology which able to impact mainly on traffic safety. In addition, a secondary radar is used which works on an idea by providing a communication signals which enables localization of objects with simultaneous data transmission of the pedestrian and vulnerable road users (VRU). An architecture approach of the system and the fundamental parameters of the current wireless are introduced in this work. This project is designed to support the IEEE 802.11p and WAVE protocols [58]
Interoperability Testing Suite for C2X Communication Components	A set of processes to acquire the performance level between the C2X communications. Some equipment have been taken part, such as interoperability test purposes on radio communication equipment [47]

Car2X-Communication OR Vehicular ad-hoc networks (VANET)	VANET is a technology that uses based on moving cars as nodes in a network to create a mobile network. VANET turns every participating car into a wireless router or node [49]. Inter-vehicular communication (e.g. VANET – Vehicular Ad hoc Networks, V2V, V2I) can be used to improve the traffic condition (To develop the safety, traffic efficiency and infotainment related applications). Intelligent Transportation System becomes an embedded of life style. Therefore, Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) communications are one of the main goals of ITS managers and has been proved that it is driving innovation in vehicles and transportation. This example presents a simulator that integrates a VANET simulator and a driving simulator Therefore, the impacts of driver as well as the vehicular network will be incorporated in the simulator performance [50], [51] and [52]

2.6   Cloud Computing

Cloud computing can be defined as "Using of scalable computing resources over Internet on a pay-as-you-go basis" [59]. Cloud computing is swiftly becoming a very attractive and foundational element in global enterprise computing. There are several companies across a wide range of industries which implement, develop and offer cloud technologies.

Cloud computing can be defined as "Web applications and server services that users pay for in order to access, rather than software or hardware that the users buy and install themselves" [60]. Cloud computing allows users to access a wide variety of applications, services, and hardware, which they might not be able to access otherwise. Cloud computing also offers great advantages for organizations and businesses of all sizes. One of the main advantages of Cloud computing is the fact that organizations and businesses do not need the infrastructure

or the necessary information and knowledge to develop or maintain the infrastructure, as providers are taking care of all that.

Moreover, Cloud computing is an enabler of innovation and new business models in enterprise computing. The true innovation and improvement that Cloud computing represents is seen in the way its computing services are being provided to the customers. By using Cloud computing organizations and businesses hugely save money and can cut the cost because they will rent the software and applications rather than buying them and installing on their machines. Additionally, using Cloud computing could save time due to the fact that businesses will not have to install and or upgrade software and applications. Furthermore, businesses can easily gain access to applications which are specified to their needs and available only over the Internet [60] and [61]. It is believed that further information regarding Cloud computing are written in different resources, see [62] and [63].

Additionally, such services comprise the ability to offer software applications, programming platforms, data storage or computing infrastructure. There are several IT system components that are being offered as services. These services are offered together as a Platform as a Service (PaaS) [62] & [63]. It is therefore useful to look at Cloud computing as a stack of layers, as proposed in [63]. Figure 2.1 depicts that the Cloud computing systems which comprise five layers: applications, software environments, software infrastructure, software kernel, and hardware.
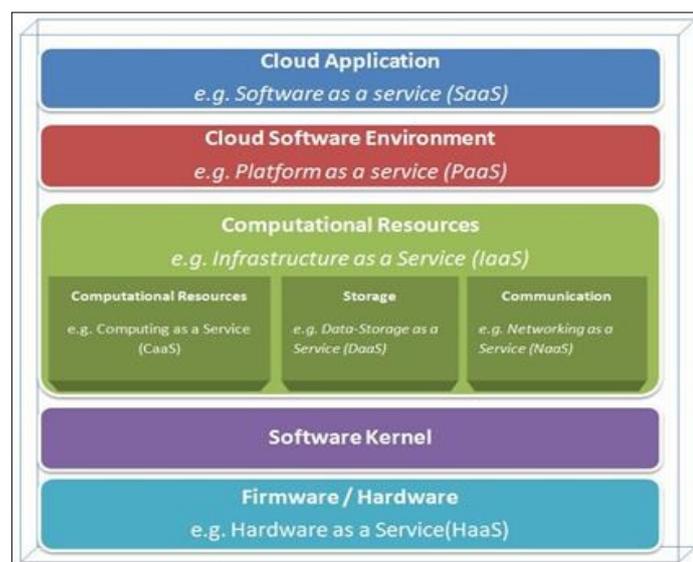
Figure 2.1 Cloud computing system [63]

2.7 Disasters and emergency response

Disaster, comes from Latin word astrum, means star. It was a common belief among the ancient that most kinds of disasters such as earthquake, tornadoes and many others are come from heavens [64]. Disasters is defined as "A calamitous event, especially one occurring suddenly and causing great loss of life, damage, or hardship, as a flood, airplane crash, or business failure" [65].

The University of Wisconsin Disaster Management Centre has conducted a training module (Disaster Management Training Programme, DMTP) called "Overview of Disaster Management" which has presented another definition for the disaster, it is "A serious disruption of the functioning of a society, causing widespread human, material, or environmental losses which exceed the ability of affected society to cope using only its own resources" [66].

Therefore, the need for disaster management system is considerably increased and it becomes a critical part of the process of sustainable community development. To this regard, the traffic management (TM) strategy is defined as "A collection of traffic management measures intended to act upon a given transport situation (traffic problems, special events or transport development states)".

2.8 Transportation evacuation strategies

A Disaster Traffic Management Strategy is "A predefined action plan for the implementation of a set of traffic management measures to improve a specific disaster transport situation" [67].

The emergency evacuation is defined elsewhere as "Evacuation is generally aimed at minimizing potential damage by removing people and their property from a high-risk area before disaster strikes and relocating them to a safe area" [68]. We will discuss this topic individually and in details in Chapter 3 and Chapter 7.

LITERATURE REVIEW

This chapter provides a detailed literature review on emergency and disaster management systems and the relevant topics. An increase in the number of disasters and their consequences has attracted the attention of both public and private sectors. Consequently, the importance of emergency and disaster response systems can be evidenced by huge literature that is available in this area and it becomes the first priority to the researchers and the decision makers. Numerous sources have focused on different key aspects related to the emergency system and implemented an improvement of simulation traffic models in order to analyse, evaluate and improve disaster management system including the traffic systems.

The National Research Council's Committee on using Information Technology (IT) to enhance Disaster Management has identified the disaster management system as "Encompassing mitigation, preparedness, response, and recovery efforts undertaken to reduce the impact of disasters" [69]. Emergency Management is defined in another source as "The implementation of plans, the use of the personal and equipment to achieve the tactical and task requirements of response to address a given threat" [70].

The Management Centre of the University of Wisconsin, United States, has also defined the disaster management system as "The range of activities designed to maintain control over disaster and emergency situations and to provide a framework for helping at-risk persons to avoid or recover from the impact of the disaster." [71]. Precisely, the term "The range of activities" contained in the definition of the disaster management indicates the effective range of applications, which may be used within the system of the disaster management in both cases, before and after disaster strikes.

Today and around the world, in the aftermath of major disasters, the need for developing and implementing the Incident Management Systems (IMS) has been increased. Reducing human casualties and disruption, the prospering of the global economic and developing smart cities is the motivation behind working on establishing and improving disaster management systems.

This chapter provides some ongoing literature reviews on the topic; Section 3.1 provides a review of types and scales for different disasters. A review of the literature on the major aspects of Vehicular Ad Hoc Network (VANETs) and Intelligent Transportation System (ITS) will be given in Section 3.3.

Various technologies and applications which are developed for emergency situation are presented in Section 3.6. Some other literature reviews have been presented in this chapter to cover some relevant topics (between Section 3.7 and Section 3.11). Section 3.13 is dedicated to present one important factor which impacts the whole evacuation process. Finally, Section 3.14 present evacuation simulation models background which are employed in different studies.

3.1   Disaster: types and numbers

An extensive array of studies has been convened by the Victoria Transport Policy Institute including the emergency response. So far, the events have been divided into several categories and the emergency transportation management reaction could be varied depending on these categories. In addition, many disasters could be a sign for other disasters. Table 3.1 shows different types of disasters which present different types of transportation issues [72].

Table 3.1 Different types of disasters present different types of transportation issues [72]

Type of disaster	Geographic scale	Warning
Hurricane	Very large	Days
Earthquake	Large	None
Tsunami	Very large	Short
Flooding	Large	Days
Forest fire	Small to large	Usually
Volcano	Small to large	Usually
Building fire	Small	Seldom
Explosion	Small to large	Seldom
Bus/train/aircraft crash	Small to large	Seldom

More disasters means more suffering. Many governments seek and work effectively to minimize the damage which has been caused to the people especially in the affected area. Data from the International Disaster Database, EM-DAT, shows clearly the increased numbers of disasters, Figure 3.1 indicates these numbers [73].
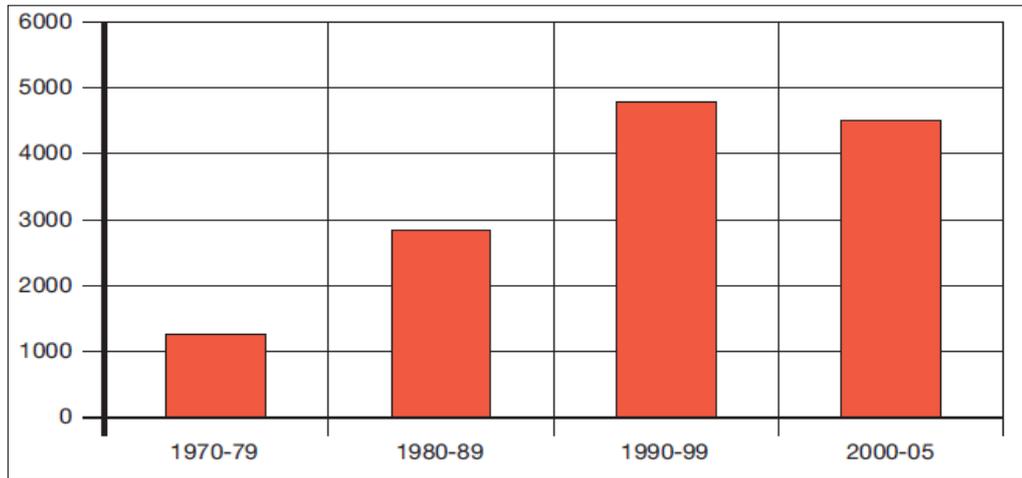
Figure 3.1 Number of disasters [73]

Note in Figure 3.2, it demonstrates rising numbers of victims for more than twenty years (between 1990 and 2012). Statistically, although some disasters can cause little disruptions to people in some countries, but because of recurrence throughout the year, it has been observed that increasing numbers of people are affected [74].
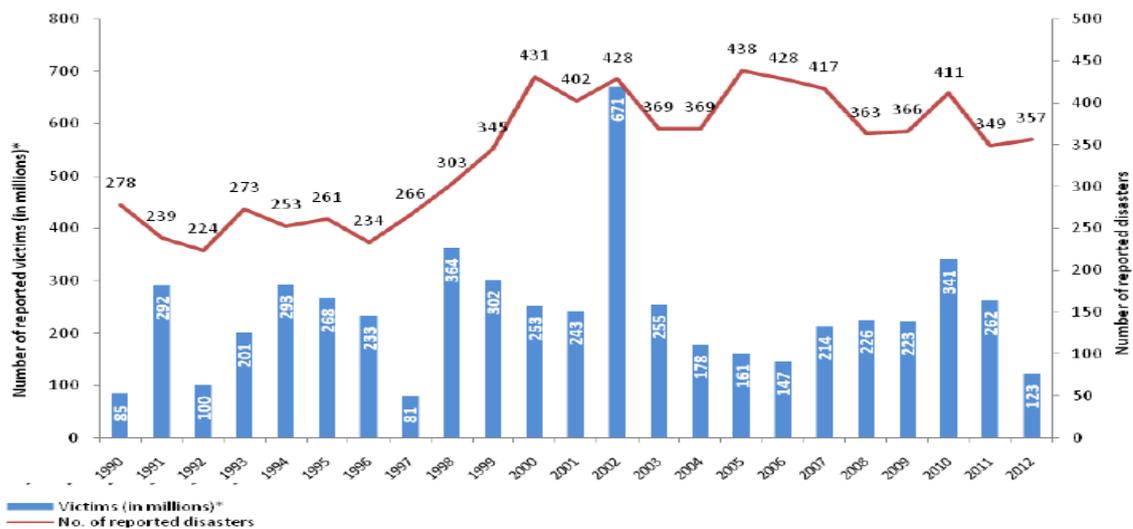
Figure 3.2 Trends in the number of reported disasters and number of victims [74]

In this regard, some countries such as developing countries may suffer from great losses in lives and homes compared to losses from the same type of disaster in developed countries because the latter have huge experience and resources that enable them to deal with such different types of disasters. Between 1999 and 2003, the average death toll had been declining (from 75,000 a year to 59,000 a year, however the numbers affected by homelessness and displacement increased, from an average of 213 million a year to 303 million a year. A report has been released by the United Nations International Strategy for Disaster Reduction in January 2010, the estimation of direct economic losses is $960 billion, and Asian countries were the hardest hit [9].

Indeed, the emergency response should occupy the forefront in all societies. However, most communities which suffer from an economic collapse have focused on major fundamentals such as education and health sectors, thus, the emergency response becomes often an afterthought, and the government and agency agenda addresses concerns about the emergency response only after a disaster happens. The Japanese news media quoted government officials report that the 2011 earthquake of the Pacific coast of Tōhoku was the worst earthquake that has struck Japan; and the potential risks from radiation leaks at the Fukushima Daiichi nuclear plant, the death toll of the earthquake were estimated at thousands of people and about 215,000 people are in emergency shelters [9]. However, some sources reported that the major industry materials, the exports of iron and other productions have been reduced, which implies that the global economy has been affected [11].

3.2   Disaster management centre

It has become very important for most governments to enhance and establish different facilities including programs, emergency policies and special emergency centres. It could be known as Transportation Management Centres (TMCs), or sometimes known as Traffic Operation Centres (TOCs).

The emergency centre takes the responsibility to develop and improve disaster management systems and services. The centre objective is to provide and share the disaster information including the information which has been collected from different resources. It has been noticed that information available from different resources will provide an incredible opportunity in loss reduction [75].

So, in order to provide sources and effectively manage disasters, more centres have been established. Agencies have built an effective emergency operation centre which will react positively to this case, such as Fusion Centres (FC) in USA. Internationally, it has been discussed to set a number of emergency operation centres (EOCs) within each state and different countries. To this end, adequate and reliable information will be dispatched from combing these centres (EOCs and FCs) [75].

3.2.1   Who needs the communications?

Although most disasters are unpredictable; whether it is a natural or man-made disaster, which makes it difficult to obtain the emergency resources swiftly and assess risks accurately. It has been recognized that communication plays a crucial role in damage reductions. In addition, providing different means of communication and maintaining communication with those outside is vital in order to send/receive important information related to the problem and solutions. Moreover, affected people will be able to send/receive the updated information regarding the disaster situation. For example, the telecom sector in China has developed some telecommunication guarantees; a guarantee for the counties, a guarantee for the townships, and a guarantee of the disaster relief [76].

The communications have played a vital role in managing and directing the evacuation operation during and after disasters. When disaster strikes, people in the affected area need to communicate with emergency agencies (centres) and/or their relatives to send/obtain the important, reliable and accurate information. The effective connections start to evacuate the affected people to the safe area, which is called evacuation areas or evacuation zones [77].

Indeed, it is a serious challenge, providing an essential communication service equally to those outside the disasters area and with those close to or around the disaster area until original telecommunication services are restored. As a consequence, two approaches have been introduced to reduce the shortage of communication services; increasing in the communication sources which is likely to be more difficult because they cannot provide an adequate communication means. However, the second reasonable option to reduce the demand of the communication is by enhancing the suppression of the network congestion during post-disaster period [78].

3.3   Disaster response and Intelligent Transportation Systems

Perhaps major accidents are the best to highlight the weakness of different systems including delivering and transforming the information. Providing the information related to the emergency situation has contributed effectively to create an entire awareness for the decision makers, rescuers and the responders, in order to increase the ability to reduce the damage and hence save more lives. Most of the jurisdictions and governments emphasised increasing use of Intelligent Transportation Systems. Substantial examples have been presented in Chapter 1.

The library of emergency response management comprises huge sources which are looking constantly at the aspects of the ITS designing goals; enhancing the safety and reducing the fatal consequences. The ITS applications aim to ease the everyday driver's life by reducing the risk of accidents, improving safety, increasing road capacity and reducing traffic jams [79].

The importance of ITS technologies has grown tremendously in particular after major disasters around the world. The ITS technologies assist and support the decision makers in managing, operating and coordinating responses processes within other agencies [80]. It ensures sustainable operations of transportation technologies at times of emergencies, avoiding the failure in the communication services in order to continue providing the information from and to the public such as using the Internet and Dynamic Signs.

Additionally, it has been noted that the potential of increasing this effective communication can be delivered through building sensor networks and communication infrastructures. It involves using wireless networks, namely sensor networks and Wi-Fi networks; providing a series of practical techniques. Also, it explains the importance of using different types of sensors rather than using one type of wireless sensors in the same site [81].

3.3.1   A historical perspective on emergency initiatives

In the aftermath of the major disasters, the transportation system is identified as one of the important dimension. Dickson and Cherrie have described the role of the transportation system in improving the emergency response.

On the other hand, it could be considered an obstruction in the implement of this process. To this end, a new system named "Emergency Route Advisory System, (ERAS)" has been developed, and it has been concluded that the emergency response should consider the transportation system as a fundamental element. In addition, this model requires a massive amount of information which could be obtainable if there is coordination and cooperation between governments, different agencies and the decision-makers [85].

A location based early disaster warning and evacuation system has been proposed for people who are already familiar with the roads and have adequate knowledge of the city facilities, and people who are not blind, by using the OpenStreetMap (OSM) [5]. Recently, the OSM has been regarded as a vital application since they have utilised this open source for different objectives while it provides free unlimited network information which has become valuable in various situations such as disasters.

In the US, the work on emergency response systems has been underway under different initiatives including the Traffic Incident Management (TIM) program. An "Incident" was defined in 2000 as "… any non-recurring event that causes a reduction of roadway capacity or an abnormal increase in demand ..." [50]. Furthermore, major events such as September 2001 have broadened the scope of TIM to the broader theme of national preparedness.

In 2003, the U.S. Department of Homeland Security (DHS) was given responsibility to develop and administer the National Incident Management System (NIMS), a framework for incident planning and response, at all levels, regardless of cause, size, or complexity. In 2004, the US Federal Highway Administration (FHWA), National Highway Traffic Safety Administration (NHTSA) and Federal Transit Administration (FTA) collectively launched the Emergency Transportation Operations (ETO) program to improve transportation safety and effectiveness of incident management and evacuation through provisions of tools, information and dynamic partnership across various departments and communities [86].

In Georgia 2007, it has been suggested to implement a new system where the emergency vehicles can be equipped with a radio-based, GPS traffic signal pre-emption system to reduce the time response. The emergency vehicles can cross the distance in less time rather than waiting for the signal especially in busy corridors [34].

The US Congress requested in 2010 the department of transportation (DOT), in cooperation with the department of homeland security (DHS) to assess mass evacuation plans for the country [87].

Although many resources showed that the United States is, in some ways, a model for emergency management to other countries, some admit some weaknesses evident in the USA disaster reduction and response systems. Conversely, in the UK, central government began seeking for emergency management system especially against the possibility of the occurrence of any nuclear attack risk after the World War II [88].

In addition, the fact is that the UK is pioneer in developing and improving the technologies, and it is necessary to discuss using of communications in emergency response. Langdon and Hoskins have recommended that an advanced communication, using wireless technologies, can be used as one of the best communication media to provide the information in real time [89].

3.3.2   Geographic Information System (GIS)

Geographic Information System (GIS) is defined as "A computer automated spatial data management software that simplifies the input by organizing, analysing and mapping of large sets of complex georeferenced information" [90].

It means that GIS is a computer – based tool for mapping and analysing spatial data faster and better than doing by the old manual method [91]. It is known by another definition. GIS is "A system that can store, display, manage and analyse geographical information where computing systems, trained people and data analysis play an important role" [92].

It has been noted that the disaster management system has utilised many different applications; tools, programs and systems, to reduce the damage. For this end, a GIS has been selected to be applied for different emergency goals; assess, analyse and assist the individuals and state levels; federal, local and state, and been able to offer a solution for the disaster problems.

3.3.3   Traffic Incident Management System (TIM)

The Incident Management System can be defined as "The process of managing multi-agency, multi-jurisdictional responses to highway traffic disruptions" [93]. Another definition has been used elsewhere, it is "The total package of measures geared to improve the effectiveness and efficiency of the overall process of handling of incidents" [94].

In order to support an evacuation plan by reducing congestion and chaos, an approach has been suggested by Yue-ming et al. This disaster management approach consists of two patterns which are as follow; either dispatching an alternative route or monitoring the traffic volume for the vehicles which are travelling at the same direction. In addition, they pointed out some problems which may intervene during the implementation of the approach. These problems may be addressed by monitoring the traffic network using either micro-simulation or macro-simulation models [95].

Basically, whenever the incident can be observed quickly, an effective and sufficient response could be provided at the incident scene. In order to achieve this goal, identifying the incident could be achieved by using a combination of devices. For example a cellular phone is one of the most important methods which can be applied to report incidents, however on their own cell-phone are not a reliable source of information. Therefore, resources can be combined, such as Call Boxes and CCTV cameras, to deliver as much accurate and adequate incident information [96] and [97]. Meanwhile, the disaster management agencies are keen to provide the electrical power, wire-line and wireless line services with adequate identification of the alternative sources.

The advantage of using Call Box project in some areas was the motivation beyond establishing the Traffic Incident Management. The incident information which can be sent by the motorists is significantly useful, and then an adequate service can be delivered.

The results show an increase in the advantages of using this project. More details can be found in the main source [98]. Some other projects are used in this area, namely them [34]:

1. **Computer-Aided Dispatch (CAD):** It provides true two-way data communication between public safety and transportation agencies.

2. **Incident - Specific Traveller Information:** Providing the information about the incident to the public users is considerably useful, allowing the travellers to choose another appropriate road, or to change the starting journey time. This could be presented through some points below:

- Predetermined alternate routes.

- Distribution of traffic incident information to radio and television outlets.

- Dynamic message signs along the roadways.

- Highway advisory radio broadcasts.

- Traveller information internet sites.

- Pager and broadcast fax alerts.

- Traveller information telephone numbers.

3. **Integrated Incident Management System (IIMS):** Based on sending incident pictures and information on the scene from a first responder to secondary responders. This information could be useful to enable the operators and managers are capable to assess the events and provide solutions for this event without the need to go to the incident.

A survey has been conducted in country's 78 largest metropolitan areas; the aim was to examine the application of three ITS technologies applied in disaster management between 2000 and 2006. Figure 3.3 shows the results of this survey which includes disaster management vehicles under applying three technologies; computer - aided dispatch (CAD), in-vehicle navigation and on-board equipment needed for emergency vehicle pre-emption [99].
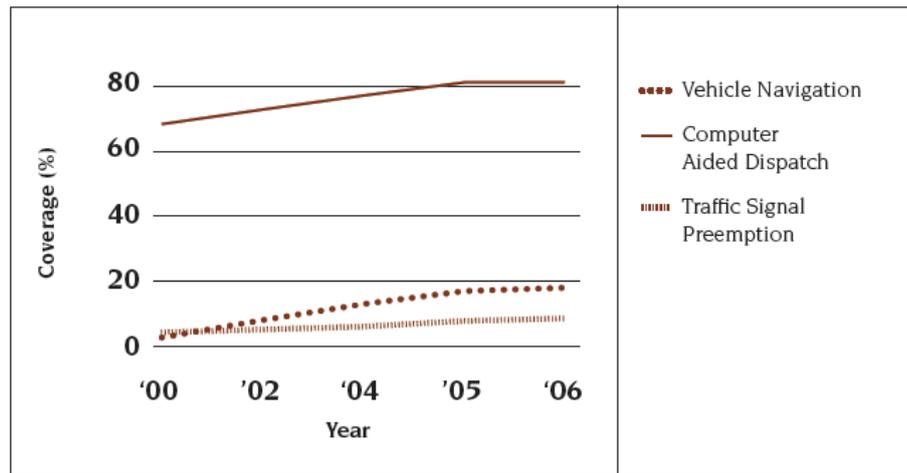
Figure 3.3 Deployment trends for disaster management systems [99]

3.4   Disaster management system: models & simulation

On an annual basis, hundreds of lives have been faced with many disaster losses. The potential of minimizing the human and economic losses has been conducted individually and by the governments, this is through a wide number of studies and researches which are emphasized on having reliable models including the simulation models. For example, Bruzzone et al. proposal, the capabilities of M&S as a support tool, will suffice to conduct and restore the effects of the huge disasters on transportation systems in a large region. The authors analysed the requested alert timing and compare the results with the time in normal scenario [100] and [101].

A prototype of web-based tool based on M&S was illustrated by Kanala et al., this prototype has been executed by responders for scenario analysis and emergency services planning [102].

Guimarans et al. proposed a software architecture which relies on a combination of simulation and optimization algorithms for road accidents. They consider the rescue team; Police services, Medical service and Fire service, while they proceeding the application of real-time decision tool to be applied in the emergency services [101].

3.5   Communication technologies for emergency

Emergency communication refers to "Communication means and methods required for guaranteeing the rescue, emergency aid and necessary communication by a comprehensive use of various communication resources in case of a natural or artificial sudden emergency" [76].

Road safety policy and traffic education, together with the newest technologies are expected to contribute effectively in developing a strong disaster management system. Altogether lead to provide the communication which is the key force during the crises. They can be accomplished as follows [103]:

- Use ITS effectively to disseminate travel related updates during an emergency.

- Establish reliable communication systems to stay in touch with the outer world in the case of emergency.

- Consider several means of communication to inform the public of emergency related travel directions and updates.

There was an opportunity to combine the traditional alarms with new vehicular communication (inter-vehicle communications and roadside infrastructure like traffic lights). It provides integration of multi responder systems to reduce the time for the emergency response trip, also alerting and warning other road users through transforming the information about the accident.

A meeting has been conducted by a panel of experts on disaster information dissemination and they have discussed different disaster scenarios in terms of communication ability with the public during the events. The experts have reported that there is a great opportunity to reduce the event risk regarding the existed infrastructure, including the use of ITS technologies and some surveillance systems, such as the Dynamic Messages Signs (DMS) and Phone Systems, which are really important and the emergency managers strongly rely on these devices, to avoid significant damage to the infrastructure and communication networks capacities. Therefore, they depend on some relatively traditional options (such as TV broadcasts, radio etc.). Also, the emergency managers could depend on the citizens as sources

of information for their friends, neighbours and the surrounding communities (person-to-person) [104].

Also, the role of initialize programs and richly detailed plans cannot be excluded from the importance of preparing a comprehensive plan for a disaster evacuation. The experts emphasized the importance of providing efficient and reliable information which should be deployed to the public. This information should cover some basic topics, such as: the threat (natural or man-made disasters), some information regarding the road and transportation states facilities and who needs to evacuate, etc.

Finally, it has been concluded that the communications technologies and plans are the biggest challenges especially in the time of disaster, and the valuable role of the Transportation Management Centre (TMC) becomes clearer in the emergency system in order to avoid the imminent threats. Therefore, increasing the interaction between the TMCs and the agencies can lead to a successful evacuation operation [105].

3.6 Technologies, services and applications for disaster management system

The telecommunication began with the invention of the telephone in 1876, and then expanded to radio broadcasts in the late 1800s and to television in the early 1900s. Today, telecommunication also includes the Internet and cellular phone networks [106].

Telecommunication is defined as "The technical basis of communication in the widest sense including: voice, text, data, and video transmission" [107].

Effective and adequate emergency responses are necessary due to the tragic reality of disasters during disaster phases. Therefore, it becomes very important to assess public emergency services capability to cope with such disasters in fast and effective services.

The emergency phases can be classified to five phases; planning, mitigation, preparedness, response and recovery [108], or as considered by some other sources; prevention, mitigation, pre-disaster, response and recovery [109] and [110]. However, a canonical for the disaster management that it encompasses four phases; mitigation, preparedness, response and recovery [111]. Further information has been presented in [84], [91], [110] and [112].

An early warning system (EWS) may use more than one ICT media. Consequently, the means of communication that have been used recently in major events may range from sending SMS messages and harnessing some of the services available in advanced mobile devices, as is the case in Europe countries, down to the use of common means of communication which have proved inadequate to meet the requirements of emergency systems such as TV, telephone and radio [113].

The attacks of September 11, 2001, brought home to the American people the magnitude of the danger which can be happened anytime and anywhere. Although, it is impossible to predict the potential of the disaster occurring, the quick emergency response reflects the interest of the private and public sectors in providing effective and accurate information [114].

A significant range of communication means; networks, services and devices, have been developed to be used in disaster management systems [71]. Background on some examples of applications, services and technologies, which already have been used in different disaster management systems, has been presented below:

3.6.1   Traditional technologies

Many governments still use various methods of communications such as TV, radio and telephone [10]. There is no doubt that radio and TV is still considered one of the traditional technologies available which have been used early in disaster management systems, basically because they are not expensive and accessible to all. In poor and developing communities and during the disaster, they took advantages of the dissemination of necessary information by radio and TV media has contributed effectively to reduce the damage, however much of the disaster information remains unavailable for all and these devices are not extensive due to lack of electricity especially in rural areas [115].

Nowadays, traditional media is still considered having effective performance even in developing countries and rural environments, because the TV is relatively low cost, they can be used to spread a warning swiftly to a broad population. The only possible problem of these means is that their effectiveness is significantly reduced at night when they are normally switched off. Also, in modern life, the use of this media has been reduced [116].

In 2010, a survey was conducted by Infogroup / ORC. It reported that to get information about an emergency, nearly 63% of people used TV and 44% of people used Radio, see Figure 3.4 [117].
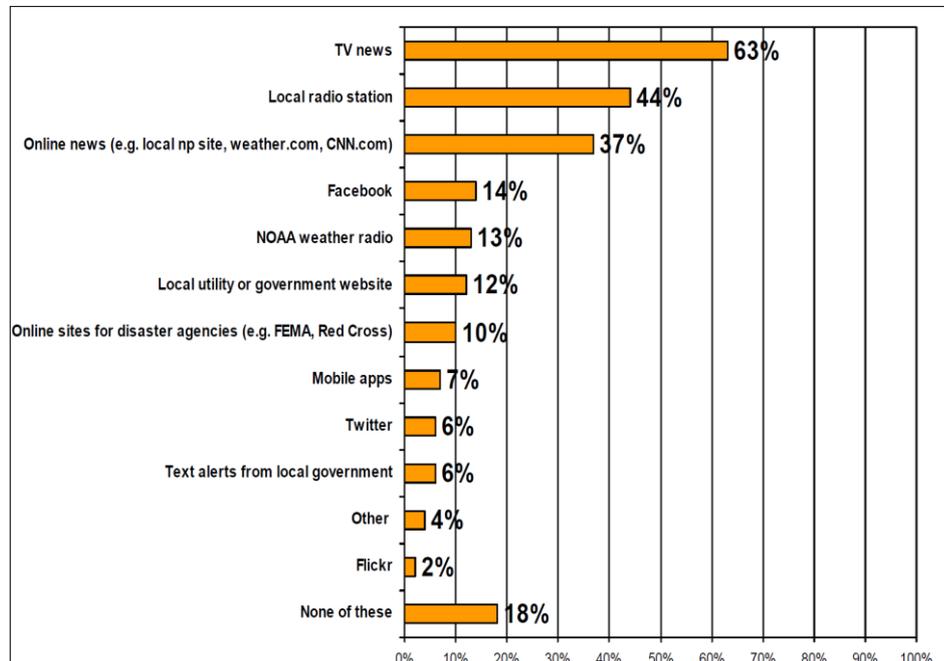
Figure 3.4 The communication media for emergency information [117]

3.6.2   New existed technologies

We are witnessing a continuing recurrence of disasters whether natural or man-made. Private sectors in conjunction with public operators are attempting to reduce the human and economic losses by harnessing and supporting the experience of using new telecommunication applications.

New technologies have offered the opportunity to adapt to the disaster situation by deploying adequate, accurate and real-time information which enhances the potential of positive usage of the communications in the disaster zone.

Generally, most of the communication networks such as the internet and communication devices are unable to work for a certain time especially during and after the disaster. It is vital to restore these networks to assist in the relief effort. Therefore, some governments and local authorities started to develop, enhance and improve preparedness at multiple levels which enable the public to address and manage disaster.

The applications of ICT perform a critical role in supporting disaster reduction. In other words, a distinctive and effective disaster management system can be designed using the new technologies.

Below, between Section 3.6.2.1 and Section 3.6.2.2, various applications and systems which are used for disaster management will be presented, as well as describe their important role in reducing damage. Furthermore, the tables below illustrate the strong and weak points for some applications during the disaster. The subsections include; A Message Board System, SMS Disaster Alerts, Beyond the 911 and Divers Applications. The details of each application will be listed below [71]:

3.6.2.1   Short Message Services (SMS)

Rapid response is one of the most important key requirements for the construction of disaster management system and the ICT enables significant, precious and crucial changes to the disaster management systems. Therefore, many governments and private sectors seek to develop a disaster management system through the use and integration of new technologies to obtain important disaster information in a short time.

In terms of emergency response, the short message's vital role can be described as "An important tool to help emergency response, and it's going to become increasingly important" the International Fundraising Director at UNICEF [73].

In 2005 and during the Katrina hurricane, the USA government realized that many residents were able to communicate with each other effectively and easily through using SMS messages. They have concluded that SMS messages perform effectively because this system is able to provide (receive or send) basic information, disaster site images and videos, voice messages and it even works on different bands [116].

In 2007, the Sri Lanka Disaster Management Centre (DMC) has developed SMS warning system after the Indian Ocean Tsunami in 2004. In addition to radio and television networks, the DMS sent SMS to government officials, media representatives, the military and the stakeholders. These agencies, in turn, contacted citizens to inform them of the Tsunami. It announced that no casualties were reported and citizens returned home over the course of the next three days. Literally, the Disaster Management Centre (DMC) in Sri Lanka realized that

mobile networks became jammed after the announcement of the disaster was issued due to the high volume of voice calls. As a result, The Sri Lanka telecommunication authority ordered that only SMS messages are used during national emergencies, so as not to overburden the networks [118].

Japan might be exposed to natural disasters, as in many other countries. Therefore, the provision of real-time data becomes one of the most prominent challenges during the disaster. The ability to get the signal connection in the disaster area is one of the most important issues of concern to those responsible for providing quick and accurate information about the disaster.

The following is a description of two applications has been implemented in the framework of the use of SMS Messages.

- A Message Board System

Application Name	The i-mode ® Disaster Message Board service
Country	Japan
Operating since	Japanese version – January 2004 English version – September 2004
Application Description	A Disaster Message Board service that permit i-mode subscribers within the disaster area to place and check messages in order to inform relatives and associates of their security and situation
Application Drivers/Purpose	The overall intention behind this application is to avoid excessive network congestion during major natural disasters as well as minimize panic among the general public due to lack of information
Stakeholders	There are two key stakeholders for this system: The i-mode users (victims or families/friends) and the authorities

Limitations	• System only activated in the event of a major calamity. • Only available for DoCoMo's users. • Users can place up to 10 messages (maximum 100 Japanese or 200 alphanumeric characters) each to be saved for up to 72 hours
Evaluation: Failure or Success?	There has been no formal evaluation of the project to date however, due to the limitations listed above the system seems to not reach success up till now
Constraints/Challenges	• Increase user's awareness of the system • Expand the system to other's operator users (compatible with other carriers) • Activate / run the system in a 24 hours basis
Further Information	http://www.nttdocomo.com

• SMS Disaster Alerts System

Application Name	SMS Alerts
Countries	UK and Hong Kong
Operating since	March 2004
Application Drivers/Purpose	The overall intentions behind these applications are to protect the employees in the firms and guide them in case of an evacuation procedure (UK case) and to give real time information about hazardously locations in order to avoid the population to go to those places along with controlling the possible mass hysteria caused by rumors (Hong Kong case)
Stakeholders	There are two key stakeholders for this system: The business corporations and the authorities (UK case) and the general public and the authorities (Hong Kong case)

Limitations	• In UK case: The system is targeted to corporate users which leaves the general public without any information in case of an emergency situation or evacuation. • In Hong Kong case: Mass information only, lack of customization or treatment of the message for different type of users
Application Description	• In UK: SMS sends alerts to businesses in London about security threats, including bomb alerts. The 24-hour service contacts all users in real time with a message that is sent within 30 seconds of the alert being received by the police. • In Hong Kong: SMS was used in emergency broadcasting. At the height of the SARS incident, the Hong Kong government sent a blanket text message to 6 million mobile phones in a bid to scotch 461 uncertainties emanating from rumors about planned government action to stop the syndrome
Evaluation: Failure or Success?	• In UK case: The system seems to have a good acceptance by the business corporations despite the fact it has a monthly fee for the pager/SMS service in contrast of its email service delivered to computers in the office which is free of charge. Corporation has a preference to sign up for the pager/text message alerts (1,121 firms in total) than for the free email alert system (589 firms). • In Hong Kong case: Although, some mistakes were committed by the authorities while sending the SMS messages across the nation as commented before, the concept was proved that if it is well implemented can effectively reach the population and avoid unnecessary human life risk because of lack of information, it can also impede rumors to multiply
Constraints/Challenges	• In UK: Expand the system to the general public. • In Hong Kong: Customize the SMS alerts by group of individuals
Further Information	http://www.egov4dev.org/mgovapplic.htm http://www.e-devexchange.org/eGov/mgovapplic.htm

This application is focused on the key points in this area; the first is that it is possible to take advantage of the application in the event of a threat of natural disasters in addition to the threat of man-made. Additionally work is underway to develop techniques concerned with providing solutions in the case of disasters in line with the characteristics of each country. Finally, the development of work is to be accessible to everyone and will not be limited to the companies.

3.6.2.2   Cell Broadcasting System

The advanced technologies have demonstrated the potential of implementing an effective disaster management system. It has been concluded that telephone (fixed and mobile) delivers reliable, effective, and affordable solutions for alerting communities about the impending danger of disasters. Even in developing countries, the losses can be reduced by using mobile phones. Below, different applications of phones in a disaster management system have been discussed:

- Beyond the 911 System

Application Name	Enhanced 911
Countries	USA, Australia and UK
Operating since	USA version – September 2004 (Phase I)
Application Description	The wireless E911 program is divided into two parts - Phase I and Phase II. Phase I requires carriers, upon appropriate request by a local Public Safety Answering Point (PSAP), to report the telephone number of a wireless 911 caller and the location of the antenna that received the call. Phase II requires wireless carriers to provide far more precise location information, within 50 to 300 meters in most cases. Basically, this system "piggybacks a cell phone's location details onto 911 emergency calls"
Application Drivers/Purpose	The overall intention behind this application is for rescue operations propose and national security

Stakeholders	There are two key stakeholders for this system: The general public and the authorities
Limitations	• Only available for GPS-enabled phones users. • Yet most local call-centers lack the technology needed to pinpoint callers' location come from wireless phones
Evaluation: Failure or Success?	Due to its currently limited implementation stage (phase1), the system cannot be complete evaluate yet
Constraints/ Challenges	• Broad definition on the concept of "Emergency services" which can excessive cause network congestion in the future. • The set-up costs involved were cited as a constraint to be solved by the US operators (i.e. Sprint) regarding further phases of the system • Private Issues
Further Information	http://www.newscientist.com/article.ns?id=mg18324663.700

This device links the public emergency services with people who are in need of relief services. The service provided by the device is its independent ability to locate the device of the caller so that there is provision in the time to respond to all callers, as well as an attempt to reduce the busyness of the network as much as possible. However, this system is still not fully implemented yet, because of the location position to the users is still inexact, and it will perhaps take a longer time to implement such a system.

• Divers Applications

Application Name	Other types of disaster efforts / systems (differing from mobile applications)
Countries	The Czech Republic, France and Turkey
Operating since	N/A
Stakeholders	There are three key stakeholders for these systems: The Telecom companies, the general public (indirectly) and the authorities

Application Drivers/Purpose	The overall intentions behind these applications are speed up decision on a disaster crisis (The Czech Republic case), relieve for victims (Taiwan case), better coordination of emergency rescue teams (France case) and by collecting data before a disaster occur the government can create a database that can be used to compare with the disaster situation later on (Turkey case)
Application Description	• In The Czech Republic, mobile device with prioritized telephone numbers were given out to 18,000 government personnel in the time of emergency • In France, New emergency response system helps fight disasters (EGERIS) was intended to increase the safety and the efficiency of civil protection organizations and authorities involved in risk management operations. The system allows emergency services to have, in real time, an up-to-date knowledge of the situation in order to take the right decision to minimize the consequences of the disaster. • In Turkey, Disaster Management Information System (AFAYBIS) is based on TABIS (Turkey Disaster Information System); A Catalogue developed for the topography and disaster management data in the accuracy of 1/5000 scaled map
Limitations	These systems are aim to help the authorities in their rescue efforts, it is not necessary focused on the general public which limit their application
Evaluation:	N/A
Constraints/ Challenges	Besides Turkey's case, all the system is focusing on the post-disaster actions. The challenge will be to develop a pre-disaster system in coordination with these actions in the future
Further Information	• The Czech Republic: http://www.jsce-int.org/Report/report/flood_euro.pdf • France: http://www.innovations-report.com/html/reports/ communication_media/report-29094.html • Turkey: http://www.isprs.org/istanbul2004/comm4/papers/339.pdf

3.7 The role of telecommunication infrastructure during disasters

Two cases can be presented in such disaster scenario; in case of ability to access to network infrastructures and devices; such as Internet, satellite and mobile phone, which provide huge advantages in term of sending serious information, meantime the case of failure in the provision of adequate communication aiming at providing sufficient, reliable and necessary information for the disaster and beyond.

In case of the failure of essential communication, networks and infrastructures of telecommunication, which is one of the most widely shared characteristics of all disasters and could be occurred through a variety of mechanisms. This aspect can be shown in several forms, as below:

3.7.1 Physical destruction of network components

At a time of disaster, and of course depending on the size of the devastation caused by the event, a partial or total destruction might be exposed to the telecommunication infrastructure.

Some disasters can harm the wire communication system, cables and underground equipment. For example, telephone systems are highly vulnerable to physical destruction, this is because they have utilised a branching structure which explains that any destruction of a single segment can disconnect the entire telephone system and can isolate the communities affected [119].

In May 2008, a deadly earthquake hit China, called Wenchuan earthquake. The government confirmed that nearly 70 thousand people died and hundreds of thousands were injured with 18,222 listed as missing, the earthquake left about 4.8 million people homeless [120]. Furthermore, In the area of economic damage, the communication infrastructures damage was monitored almost 3897 telecom offices were hit, In addition, 28,714 mobile and PHS (personal handy-phone system, a kind of cordless telephone system) base stations were ruined, 28,765 sheath kilometres of optic cables were damaged [76]. Therefore, the internet service has introduced a solution to the design and operation of telecommunication networks.

While wire networks have a high degree of vulnerability to physical destruction, and in addition to Internet services, wireless networks are highly recommended. Therefore, the destruction of an antenna site only reduces communication services in a limited area.

The solution basically is based on maximizing the redundancy in network communications, and adding an advanced routing technique, so networks can suffer severe damage before portions of the network become disconnected [119].

In the 1999 NATO bombing of Belgrade, communication systems were totally damaged by targeted strikes, Internet service providers device a quick solution through using secondary links, such as satellite links, cellular networks, and even an amateur packet radio. In September 2001, broadcasting of multimedia abilities was disrupted; this is because the television and radio broadcast antennas were allocated in One World Trade Centre. By contrast, McCaw Cellular lost 2 of its 400 cell sites in the Northridge earthquake, resulting in only isolated service disruptions [121]. Therefore, to reduce the effects of disasters, it is recommended to implement a communications network with wired and wireless infrastructure which increases the ability to deal with the destructions. And many researchers concluded that the internet is the best in the proof of its abilities to overcome the devastation and to work again soon after the rehabilitation of the communication networks.

3.7.2   Traffic jam

Normally, when a disaster occurs in a particular area, attention goes mainly to try to get information about the disaster and to coordinate the emergency response services, both internally and externally, through communications.

In other words, the ability to communicate is a technological ability in this stage. Therefore, the people who are inside or outside the affected area, relief organizations, and others are in desperate need to use communication devices in various forms in order to manage the rescue operation and the evacuation processes to reduce the losses in all its forms.

However, significant challenges have resulted after major crises. The performance of communication networks, such as Internet and cellular networks, can be advisedly offered resulting in congestion failures.

In September 2001, because of the network failure by network congestion which make the United States Federal government to move quickly to develop a priority access for key public officials. It is modelled after the Government Emergency Telecommunications Service (GETS) which gives priority access on the landline telephone network, while the Wireless Priority Service (WPS) was designed to manage access to the cellular network in an emergency [119].

As One Analysis Argued, "The Earthquakes of Kobe, Mexico City (1985), San Francisco (1989), And Los Angeles (1994) indicate that telephone networks are not so much destroyed as congested into uselessness" [121].

3.7.3   Disruption in supporting network infrastructure

In this section, because of the destruction which is caused by disasters, the failure in communication networks and the infrastructure reflect the weakness and interruption of external supply received (i.e., infrastructure are still exists physically but is not operational). Also, there is no doubt that the provision of energy for communication networks devices is required, for most of communication facilities, for example, electrical power is required to operate all modern telecommunications facilities.

The European Commission Information Society pointed out in the ARECI report [122] that the outcome of not implementing a disaster relief plan could lead to possible occurrence of the worst in the event due to delay in relief operations. As a consequence, delays in response result in more lengthy outages and may result in wider spread outages. In the 1989, Loma Prieta earthquake, 154 of 160 central offices in Northern California lost power. Even worse, back-up power systems at 6 of those 154 failed [121].

3.8   Wireless communications

Disaster varies in severity, scale and durations, therefore different emergency measurements have been adopted and implemented for different countries. It has been recognized that wireless communication is the most effective in the emergency response such as satellite communication, WiFi, and WiMAX, and all have played a significant role in disaster relief.

3.8.1   Mobile Ad Hoc Networks (MANETs)

It can be known as *"short lives"*, can be defined as *"A mobile ad hoc network is a set of mobile nodes able to communicate with other nodes in their surroundings, these wireless communications happen in a peer-to-peer manner, without relying on any predefined infrastructure"* [124]. This kind of wireless network can be configured without existed infrastructure, in turn, achieving the dream of getting connected "Anywhere and Anytime".

Typical application examples include a disaster recovery or a military operation. As an example, we can imagine a group of people with laptops, in a business meeting at a place where no network services are present. They can easily network their machines by forming an ad-hoc network, this is one of the many examples where these networks may possibly be used.

IEEE 802.11 "Wi-Fi" protocol is used in providing ad hoc network promising when no router or access point (AP) is available. Nowadays, smartphone devices are very common and most people seek to have a device most standard applications are available within these smartphones such as GPS, and wireless communication technologies; such as Bluetooth and Wi-Fi. In the case of a disaster in urban areas, MANET would be useful as it has been assumed that many people have these devices, an effective means of evacuating to nearby safer refuge areas and of communicating disaster information [125].

Some studies proposed specific technologies which focused on providing solutions to this problem. Serhani et al. proposed a service discovery and reservation technique for mobile ad hoc networks (MANET), tailored to support disaster recovery and military operation environments. Their technique locates the resources, taking service levels and requirements into account. They build a purpose built simulator to evaluate their technique and report its usefulness in locating and reserving services in varying network density, rate of requests and other operational conditions [126].

3.9   Vehicular Ad Hoc Networks (VANETs)

From the perspective of transportation, a remarkable increase is recorded in the number of vehicles leading to significant increase in congestion and road accidents, and that would

contribute increase the threats to road users (drivers, passengers and pedestrians) [127].

Vehicular ad hoc networks (VANETs) can be defined as "An emerging field of mobile ad-hoc network. It is built for enhancing the traffic safety and efficiency with an assumption that each vehicle has the capability to communicate with others via wireless channel. Safety-related and traffic information are disseminated and shared in the network. Every vehicle collects information and cooperates to achieve safety and efficiency" [128], see Figure 3.5 to enhance the definition.

The inherent human desire of human for change, progress, mobility, entertainment, safety and security leads to the development of Intelligent Transportation Systems (ITS). Traditionally, traffic information is only available through inductive loops, cameras, roadside sensors and surveys. With recent technology developments, the ITS has increased the ability of providing a new venue to collect real-time information from on board vehicle sensors, and effective propagation of information.

Intelligent Transportation Systems (ITS) provide a set of technologies and protocols for vehicular communications. The main focus of research activities, within ITS, has been on development of safety, traffic efficiency and infotainment related applications. Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) communications are the main research goals of ITS [129].
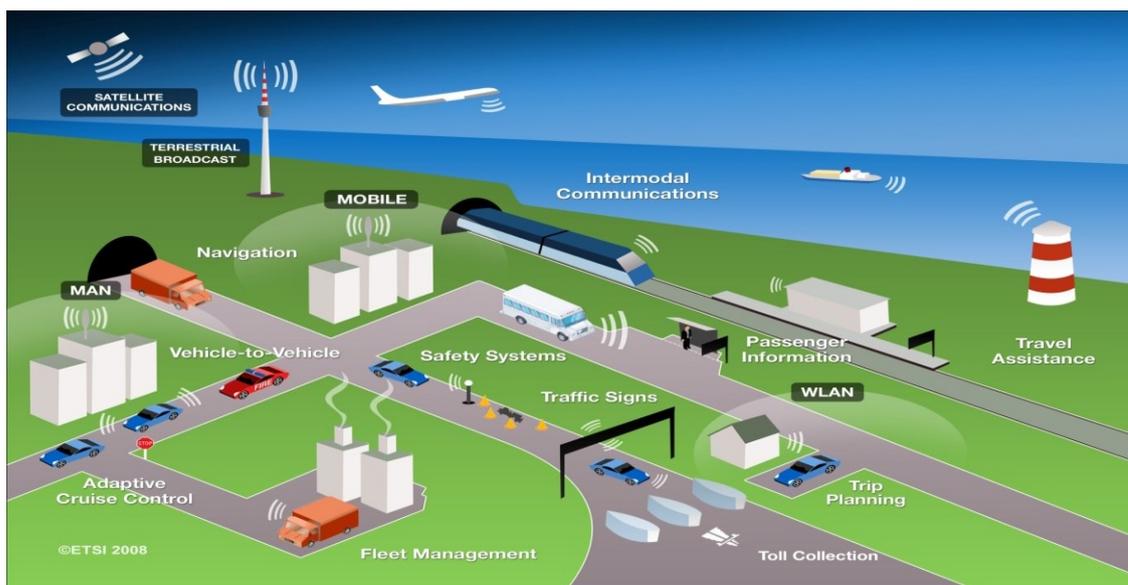
Figure 3.5 Vehicular Ad Hoc Networks [130]

Another definition for VANETs is described elsewhere "VANETs are distributed self-organizing networks formed between moving vehicles equipped with wireless communication devices, and this type of network is developed as part of the Intelligent Transportation Systems to bring significant improvement to the transportation systems performance" [130].

Today's technologies, especially wireless technology, have contributed effectively in the provision, support and facilitating the communication in-vehicles; (V2V) and (V2I). This can be offered by introducing a long list of applications varying from transit safety to driver assistance and Internet access. In these networks, the vehicles are equipped with communication equipment that allows them to exchange real-time information with each other in Vehicle to Vehicle communication (V2V) and also with a roadside network infrastructure; Vehicle to Roadside communication (V2R) [131]. They are sometimes known by non-infrastructure solutions which are capable to minimize the traffic congestion problems [132].

Additionally, in – vehicle equipped devices, VANETs, were used in other emergency systems. An approach was proposed where it is based on the theory that in the event of traffic chaos arising, the aim is to disseminate spatio-temporal traffic information related to first responders using VANETs, it is called a "Reduce Traffic Chaos in Emergency and Evacuation Scenarios" approach. In this approach, a technique has been introduced to clear a path for an emergency vehicle which could reduce chaos. This distinctive approach has clear proven advantages if there is no messages relying on the infrastructure [133]. In such a system, Reduce Traffic Chaos in emergency and evacuation scenarios, VANETs is used specifically by applying some developed technologies such as Wi-Fi IEEE 802.11 and WiMAX IEEE 802.16 for improving the communications, and despite of these applications which have proved their significant potentials, some challenges have been presented and discussed as well in [134], the proposed scheme is evaluated using simulations.

Park et al. investigated a serious problem of reliable transmission of multimedia data in VANETs for safe navigation support applications. Their approach is based on network coding and is evaluated using simulations [135].

The importance of applying VANETs has been described in many sources. The challenge here is to propagate the accident information in real time. Tseng has identified two types of multi- hop broadcasting scheme for emergency broadcasting; sender-oriented scheme and receiver-oriented schemes [136].

Buchenscheit et al. proposed an emergency vehicles warning system that exploits vehicular network technologies. The emergency vehicles could transmit radio signals and detailed route maps to other vehicles and signals in their path in order for those vehicles and people to take appropriate and timely action. A system prototype has been built and tested in a traffic environment comprising emergency vehicles and traffic signals. However, the system was conducted specifically for emergency vehicles. The prototype implemented offers a significant time reduction in emergency situations. An alternative route could be introduced in addition to identify the reaction of other drivers [137].

3.10   Mobile computing

Because of continuing innovation in technologies, particularly the wireless technologies, a considerable amount of leverage in reducing the loss of life and economic damage was obtained which leads to increase the ability of providing and updating the useful information.

Basically, mobile computing refers to "Users with portable computers still have network connections while they move" [138]. Another definition for mobile computing is "An umbrella term used to describe technologies that enable people to access network services anyplace, anytime, and anywhere" [138].

Although laptop computers, notebook computers and smart phones can be considered various kinds of mobile computing devices, laptops and notebooks are sometimes removed from the group of mobile computing devices as they cannot be used while in motion (cannot access the Internet) [139].

Due to the broad coverage of the mobile phone network and the mobile phones are available in most pocket of all people, they can be used in the implementation system for disaster management [140].

A study, conducted in Bangladesh, states that the wireless mobile technologies can be utilised in disaster information management [115]. The proposed results show that the mobile technology can be employed to disseminate information for pre and post disaster; exchanging the disaster information.

Various disasters damage reduction illustrates the importance of providing the mobile devices before, during and after the disasters. The emergency status depends on network data availability in such difficult conditions. Four different stages require different connection means, which are as follows: Early warning, Disaster impacts, Immediate aftermath and Recovery and rebuilding, see Figure 3.6 [73]
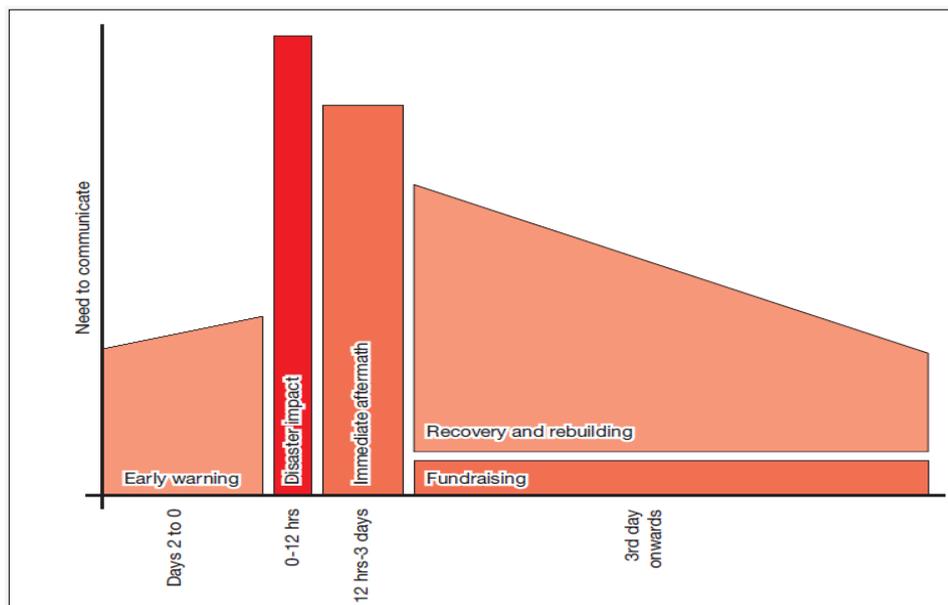
Figure 3.6 Communication needs at different phases of a disaster [73]

Figure 3.6 shows the size of the need for communications for disaster phases. It shows that the communication is necessary and critical at the time of the disaster's immediate impact compared to the recovery and the early warning phases. However, the inadequate performance of some mobile phones in the disaster scenario is explained by several reasons, the most important are; users have not employed them effectively, high cost production and the governments and stakeholders have reduced the potential of developing such devices and applications [141].

3.11   Web – Based Travellers Information Services

Web-based Travellers Information services are set to play vital roles in propagating the transportation systems information. In order to investigate the public's opinion on the significant providing the travel information, Fekpe and Collins have established a number of surveys and telephone interviews. To achieve the target, a complex network has been utilised to send and receive the traffic information. And then, the data is provided from various medias such as smart radio broadcasts and helicopter surveillance to other medias through TV and Internet. To conclude their findings, accordingly to the customer awareness, access, acceptance use and value of the information, they noticed that travellers, general public and stakeholders have shown different percentages of the level of interest in using the web-based information [142].

3.11.1   Social Networking

Social networking (SN) is "The grouping of individuals into groups based on interests, profiles, etc. It is mainly oriented to meet other people and to share first-hand information or experiences about common interests" [106]. Another definition for social networks has been described in [143] and [144]. Examples of social media include blogs, chat rooms, wikis, YouTube Channels, Linked In, Facebook, and Twitter. Social media can be accessed by computer, tablets, smart and cellular phones, and mobile phone text messaging (SMS) [145].

The increasing complexities of modern life, the desire to connect, communicate and build relationships with peers, become one of the important features of society. Therefore, various technologies have been designed to meet the requirements of sharing and exchanging the information in different aspects. The United States, as many developed countries, have contributed significantly in developing, enhancing and providing services for the participants in social networks, especially through the Internet. Facebook, MySpace, Pinterest and Twitter are the most prominent examples of social networks [106].

Now, we will turn the attention to the role of using social networks in various aspects. In Section 3.11.1.1, we discuss works which specifically done in transportation system, and the challenges can be raised during using social networks is presented in Section 3.11.1.2.

3.11.1.1 Social networks in transportation system

Advanced technology has performed explicitly by reducing the constraints between users especially via Internet services, and it motivated people to increase the time spent in vehicles. Therefore, it can be concluded that vehicles are the third place where people could spend more time, after the home and workplace [106] and [146]. As a result, it becomes necessary to clarify the importance of providing essential information for drivers.

Smaldone et al. have described the communication between the drivers as "*In this socially-driven virtual world, people can form "Instant villages" that mirror and facilitate real-world interaction*" [146].

For providing the social networks in a vehicular environment, some companies have already launched some applications which depend on adding some basic social features to navigation applications and services. Several applications have been generated in the vehicular environment, Table 3.2 shows the most common social networks applied [106].

Table 3.2 Classification of social services for vehicular environments [106]

	Personal information	Traffic information	Photo	Voice notes	Integration with other SN
Navigon	Location, destination				Facebook, Twitter
ALK Technologies	Location				Facebook
Telmap & GYPSil	Location, recommendation, events, news, advertisement		Yes	Yes	Facebook, Twitter
Aha Mobile	Location, recommendation, events, songs	Congestion		Yes	Facebook, Twitter
Waze	Comments	Hazards, accidents, speed, cams, map inconsistencies, congestion, parking	Yes	Yes	Facebook, Twitter

Table 3.2 displays different social networks used in vehicular environments as well as providing important information by integrating with other social networks. According to the features of the social networks shown above, it is demonstrated that Aha Mobile and Waze are most useful in vehicular environments.

3.11.1.2 Challenges and design issues

It has been recently reported that the social networks for vehicle drivers while they are concentrating on the road has become as an urgent need as the provision of social networks in the home and office work or in public areas [106]. Therefore, some recommendations have been suggested for commuters in order to provide successful social network services, such as the ability to avoid touching the screen, presenting the information according to the size of the screen, using speech technologies to communicate with drivers about information.

Moreover, some automotive companies have started moving towards the provision of network equipment in the vehicles, such as an on-board computer, it still requires some time to be available in all vehicles. Therefore, they have suggested that specific software can be included with some high penetration rate such as Personal Navigator Device (PND), Smartphone, etc., so they can use it for vehicle scenarios.

In order to overcome the difficulties and problems that may accompany vehicles while can communicate and share other information, the support approach would be provided by the technology and it is currently available or under deployment, Table 3.3 shows wide variety of applications which can be applied on Smartphone and in-vehicles. According to the results of Table 3.3, the Smartphone has been presented as the preferable alternative because of high features such as time, cost to market and capabilities indicators.

In addition, they proposed a social network application called Drive and Share. This application has been developed for iPhone to allow the drivers to send/receive the vital information on board vehicles in real time, such as personal and traffic information [106].

The traffic information enables the navigation systems to recalculate the best path and subsequently update all the relative information; services facilities. Precisely, different information can be gathered through the vehicles, passengers and drivers which are currently moving along these alternative roads.

Table 3.3 Comparison of application platforms [106]

Application Platforms	Integration	Open Platform	Time to Market	Technical Capabilities						
				Accelerometer	GPS	Multitouch Screen	Speech Technology	Customizable	Cellular Communication	Multiple Hardware Platforms
	Indicates whether the platform has been deployed (or is planned to be deployed) on smartphones or in-vehicle equipment.	A platform increases its value when provides some degree of openness in terms of: • Be based on standards. • Allowing the development of third party applications. • Open source code and allowing its modification.	• Mature: available some time ago. • Recent: available, but growing. • Short term: available in the next year. • Medium-long term: not available in the next two years.							
iPhone OS	Smartphone	Third Party Applications	Mature	Y	Y	Y			Y	
Android	Smartphone and In-vehicle	Open Source	Recent	Y	Y	Y	Y	Y	Y	Y
Microsoft Auto	In-vehicle	Open Source	Recent	Y	Y		Y		Y	
MeeGo	Smartphone and In-vehicle	Open Source	Short Term	Y	Y	Y		Y	Y	Y
European ITS Reference Platform	In-vehicle	Standard	Long Term	Y	Y				Y	Y

3.11.1.3 Social networks role in disasters

Social networks within vehicles have become more reality with high penetration rates, although it still faces many challenges which need to be taken into an account, particularly, the provision of social network services in the vehicular environment.

In the early 21st century, social networks have played a crucial role in emergency response and disasters. They rank fourth among the most common means of communication in emergencies [145]. The social networks can be used in emergency responses for the disasters through disseminating a wide range of public safety information, responding to victim requests, and using uploaded images in order to create damage estimation.

To date, many sources confirmed the vital role of using social networks in the case of disasters, and it has been verified that the use of social networking is significant to achieve success in responding to any incident. During Hurricane Gustav, in 2008, one of the most

famous of the social network, Facebook, was used by the Community Emergency Response Team (CERT) to send a notification to team members when its call notification system went down [145].

In 2010, a survey conducted by the American Red Cross showed that many people might turn to social networks to ask for relief for themselves or others during events. The survey found that if people couldn't dial the 9-1-1 firstly, then one in five would turn to get the response through digital means; such as emails and social media [147]. The survey also found that social networks have occupied the fourth place among popular media which can deliver the emergency information, just behind television news, radio and online news sites.

3.12   Transportation evacuation strategies

The Transportation Evacuation Strategies can be simply defined as "Moving the threatened people away from the dangerous area" [149]. It can be enhanced by implementing one/more evacuation schemes. The definition involves some important and complex steps that require intensive study to get the best evacuation strategies that enable us to achieve the fewest possible losses.

3.12.1 Evacuation types

Evacuation is considered one operation among different processes which needs to be undertaken during the disasters. So far, a range of evacuation forms has been conducted, listed below [10]:

- Spontaneous Evacuation

- Voluntary Evacuation

- Mandatory or Directed Evacuation

- Notice versus No-Notice Evacuation

- Shelter-in-Place

3.13   Transportation evacuation factors

This section aims to present some factors impact which could increase the potential of our disaster management system performance; especially focus on the Average Vehicle Occupancy influence on evacuation time.

3.13.1 Average Vehicle Occupancy (AVO)

Average Vehicle Occupancy can be defined as "How many persons are being transported by the private vehicles counted or surveyed as traveling in different geographic areas, on different types of roadways, for different trip purposes or at different times of the day" [150].

This section aims to present the AVO influence on evacuation time; in other words, to what extent this factor contributes in reducing the time required to evacuate the vehicles as this factor is an indication of how many people could be evacuated by using the available vehicles to safe places; this measure ignores vehicles such as motorcycles, and hence increase the effectiveness of our proposed system; i.e. Intelligent Disaster Management System.

High AVO indicates that more people are ride sharing, and hence increase the number of people, who are under risk conditions, to move out of the affected area. In addition, it is assumed that AVO should generally be higher in HOV Lanes (High Occupancy Vehicles); where the disaster management system allows the vehicles to use these lanes in special occasions such as disaster situations, than in General Purpose Lanes.

We reviewed some references about the AVO value [152] and [153], all of them assumed the AVO values between 1 and 3 according to past census and the high vehicle ownership in the households. Guhas conducted many studies on the evacuation of Virginia Tech Campus. He estimated the car occupancy factor according to available parking spaces, in his case the number estimated was too small in the evacuation process of a city, since a variety of vehicle compositions are available and could be used for the evacuation.

A regional evacuation modelling has been investigated by Southworth [152]. He pointed out that there are two possible constraints on the number of home based vehicles used during the evacuation process: the number of vehicles left at home, and the number of licensed drivers among the non-work, non-school population. He observed that there are, on average, 1.03 vehicles per licensed driver in the United States, that the average household contains 1.25 workers and owns 1.87 private use vehicles, and he assumed 1.25 commuters per vehicle, gives approximately 1 vehicle per household used in the work trip (i.e., 1.25 workers per household, l.25 workers per commute vehicle): leaving approximately 0.87 vehicles available, on average, to non- working household members. Also, He mentioned that at home licensed drivers (approximately 0.54 per household), driver availability in the USA as a whole, still slightly more constraining than vehicle availability. His calculations led to suggest a reasonable lower bound on the average home based vehicle occupancy rate of close to (1/0.54) = 1.85 day time evacuees per vehicle.

The above studies do not take into account a number of important factors, such as the distribution of vehicle ownership by household size, the spatial separation of driver and vehicle at the time of the event (especially if a rapidly developing one), or an unknown percentage of vehicles currently out of order, suggests an "Average worst case" (lower bound) at home based vehicle occupancy rate of 1.8 persons per daytime evacuating vehicle [153].

Moreover, the rate of car occupancy in Europe is slowly starting to steady after a downward trend. Between 2004 and 2008, the recorded data for the average number of passengers per vehicle for the Eastern European countries (Czech Republic, Slovakia and Hungary) showed that AVO is approximately 1.8 passengers per vehicle, see Figure 3.7. This is considerably higher than the average number of passengers per car for the Western European countries (UK, the Netherlands and Germany) which were 1.54 passengers per vehicle. Although the data sets are incomplete and long term occupancy trends are only available from a very few countries, the figures show, as would be expected, that car occupancy rates have declined over a period when car ownership increased [154].
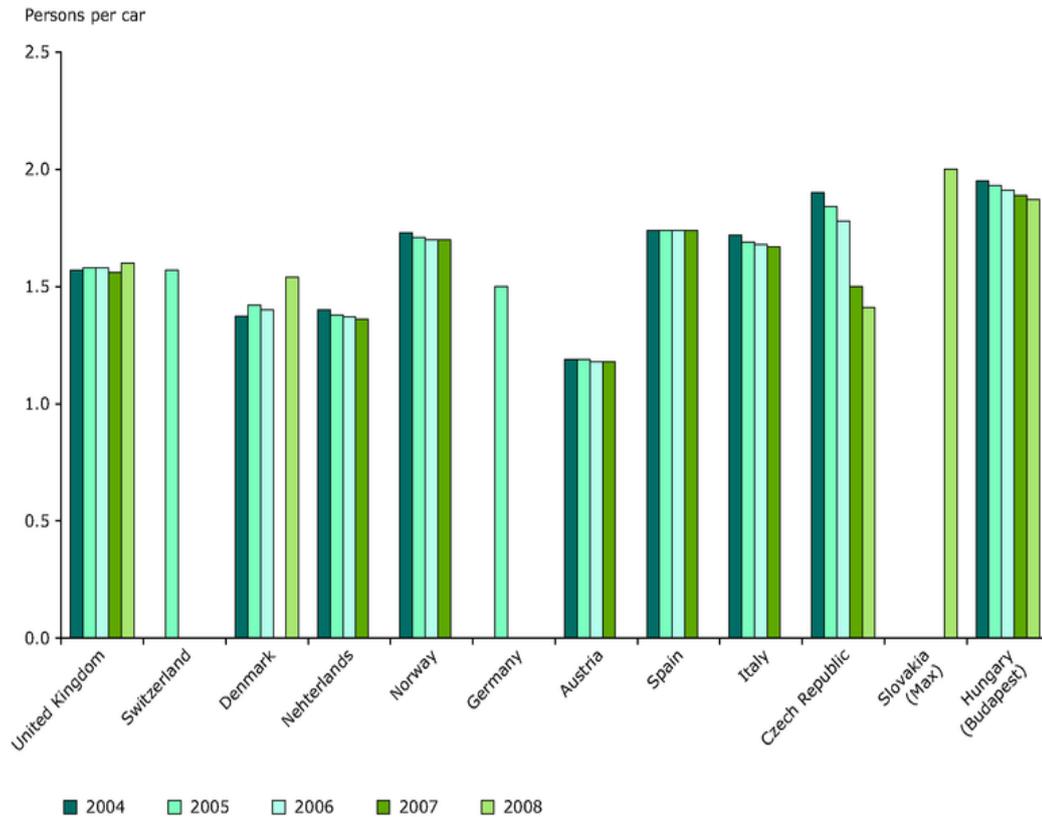
Figure 3.7 An average number of passengers per vehicle for the Europe cities [154]

This study presents some basic calculations in Section 6.4, and we will evaluate and discuss the importance of this factor in Chapter 9.

3.14   Transportation evacuation models

A long history has been recorded for the damage caused during disasters. In Pennsylvania in the USA, 1979, a nuclear incident hit along 3 miles, and important inadequacies issues were revealed in the disaster response system. Since then, many researches have been conducted on different disaster scales.

Moreover, within the transportation area, a number of researchers approached the evacuation strategies limitations and have improved evacuation models using either traditional traffic assignment or simulation approach [151].

Regarding the optimal scheduling difficulty which is dealt through Dixit and Radwan proposal, through simulation and optimization algorithms, a real time decision support system has come as evidence that its usefulness is an essential tool to develop evacuation operation efficiency [155].

For the large-scale vehicular network simulations, an analysis methodology approach has been suggested by Perumalla and Beckerman. This approach has been used to employ a solution to the decision makers, as well as tracking the refinement of simulation result quality. This methodology has been used in across multiple runs and in order to detect the timing of evacuation the methodology has been simplified to be used for the evacuation scenario [101] and [156].

General and specific simulation models have been developed over the last two decades, significant developments in computer have been produced including visualization have facilitated to create the computer based models; such as simulation models [157]. Pham et al. reviewed 11 current evacuation simulation models (were developed between 1980 and 2007), and these models consists methodologies used in current available large-scale simulation evacuation models and decision support systems, these models are summarised in Table 3.4 [158].

Table 3.4 A summary of the evacuation models reviewed [158]

Model Name	Year	Usage	Authors
NETVACI	1982	Network Emergency Evacuation model based on a simulator capable of estimating traffic pattern and evacuation time on road network surrounding nuclear power plants	Sheffi et al.
CLEAR	1983	Calculates Logical Evacuation and Response model is based on a microscopic simulator for evaluating network evacuation time during a nuclear emergency	McLean et al.
NESSY-IV	1983	Net Structure Analysing System IV model based on a macroscopic simulator is suitable for small area and works properly for earthquake emergencies	Hiramatsu
I-DYNEV	1980	Interactive Dynamic Network Evacuation model is used for emergency planning and evacuation in case of nuclear power plant incidents	Lieberman
MASSVAC	1985	Mass Evacuation model is a tool for the assessment and analysis of urban area evacuation plans	Hobeika and Jamei; Hobeika and Kim
TEVACS	1990	Transportation Evacuation System model is used for emergency management and evacuation is case of nuclear incident. It is based on an advanced version of the NETVACI simulator	Han
REMS	1991	Regional Evacuation Modelling System model is a decision support tool mainly used for traffic control and management in case of emergencies	Tufekci and Kisko
TEDSS	1994	Transportation Evacuation Decision Support System is based on MASSVAC model and used for traffic management and evaluation of evacuation time for nuclear power plants in Virginia	Hobeika
OREMS	1994	Oak Ridge Evacuation Modelling System is used for emergency management in large scale evacuation process.	Rathi and Solanki; Rathi
CEMPS	1996	Configurable Emergency Management and Planning System combines a discrete event simulation model and Geographic Informative System to support evacuation planning management	Pidd et al.
D4S2	2007	Dynamic Discrete Disaster Decision Simulation combine san ARENA simulation model with a GIS and SQLServer database to simulate evacuation process and resources deployment	Wu et al.

This report produces a SPreadSHeet (SPSH). It involves different techniques/strategies that could be applied to improve and support the evacuation management system. Particularly, it provides significant and efficient emergency responses, and hence increasing the potential of different traffic network devices to guide the evacuees to safe destinations. The sheet demonstrates different scenarios and connecting to a simulation model; S-Paramics ITS System, to compare their performance.

METHODOLOGY AND MODELS

This chapter provides the theoretical background to the modelling and simulation methods that have been employed to model different disaster and evacuation scenarios, and demonstrating our proposed system. The chapter provides a broad introduction to the area of traffic modelling covering various modelling and simulation methodologies. A range of techniques have been used to model and evaluate different disaster and evacuation strategies scenarios including a tool based on OmniTRANS and S-Paramics softwares.

Chapter Three presents the applied theory of traffic flow modelling and simulation. It reveals the important theoretical models used to present the principles of the traffic network. To this end, the principal variables that have been considered for the traffic flow will be illustrated (which form the traffic flow theory). Then, the report gives the basic traffic formula and provides the primary relationship between these variables. Moreover, the models that have been developed have been reviewed which they suited for analysing the behaviour of the traffic flow, especially in such disaster scenarios. All these materials will be presented and described through the sections below. Consequently, we will define and present various algorithms and models that have been considered in order to justify an explanation for the implementation models.

Sections between 4.1 and 4.3 present a review of the basic traffic flow theory variables that have been provided by [159]. We define the fundamentals of the traffic flow, the relations and the formulas between them. Sections between 4.3 and 4.7 give a review of traffic simulation and summarize the advantages and disadvantages of major models. The rest of the chapter is devoted to the available data which have been offered by different resources. It summarizes the details of each city such as location maps, layouts, etc. The data have been used to provide the necessary input for using the micro-simulation and macro-simulation models, and to test the developed model.

4.1   Traffic flow theory

The traffic flow characteristic shows the dynamic change at different time intervals through the day. Although traffic flow by its non-linear nature is complex, traffic congestion can be a certain extent predicted and controlled as the drivers tend to behave within the stream range.

However, the catch is that this is true only if the variables on which their representation depends are known with infinite precision. Meanwhile, the challenge here is how to deal with these unstable different traffic problems. The important issue which establishes the core of different techniques is to define and understand the traffic variables conditions. The main variables which can emerge and impact on the performance of the traffic road system will be defined in the next section and their relations will be presented.

4.1.1   Traffic flow primary variables

Many variables play a fundamental role in characterizing, modelling and studying the dynamic of traffic. In our problem, the most important variables are; speed, flow and density. They are essential for designing, analysing and controlling the transportation systems, they will be detailed below:

- **Speed** can be defined as "The rate of change of its position" expressed as the distance per unit time. Generally, it is expressed by kilometres per hour (km/h) or mile per hour (m/h). The symbol of the speed is (υ), and the free flow speed is designated by (v_{max}). Speed is one of the most important variables which can measure the performance of different types of roads.

- **Flow** is "The amount of traffic passing a point or on a lane or roadway during a designated time interval". The symbol for flow is (q), and the maximum flow is (q_{max}). It is expressed by the number of vehicles using the road per specific time.

- **Density,** the third main variable, it is "The number of vehicles occupying a length of a lane or roadway at a particular instant". It is expressed by the number of vehicles per kilometres. The symbol for density is (ρ).

4.1.2   Relationships between Speed, Flow and Density

Speed, flow, and density are all related to each other. The relationships between speed and density are not difficult to observe in the real world.

4.1.2.1   Basic formula

The formula below shows the relation between the variables:

$$q = \rho \, * \, \upsilon \ldots \ldots \ldots \ldots (4.1)$$

Where:

     q: Flow

     ρ: Density

     υ: Speed

If two variables can be known, then, the third variable can be calculated through the basic equation above.

To facilitate collecting the main traffic data along the road, it is adequate to select collecting two of them and the third variable can be determined using the diagram (Figure 4.1). Thus, the diagrams show the continuous curves and most of these main elements under the effect of changing environmental conditions, non-homogeneity of vehicles in the traffic stream. Figure 4.1 shows the relationships between the main basic road variables [160].

- Speed-Density diagram
- Speed-Flow diagram
- Flow-Density diagram
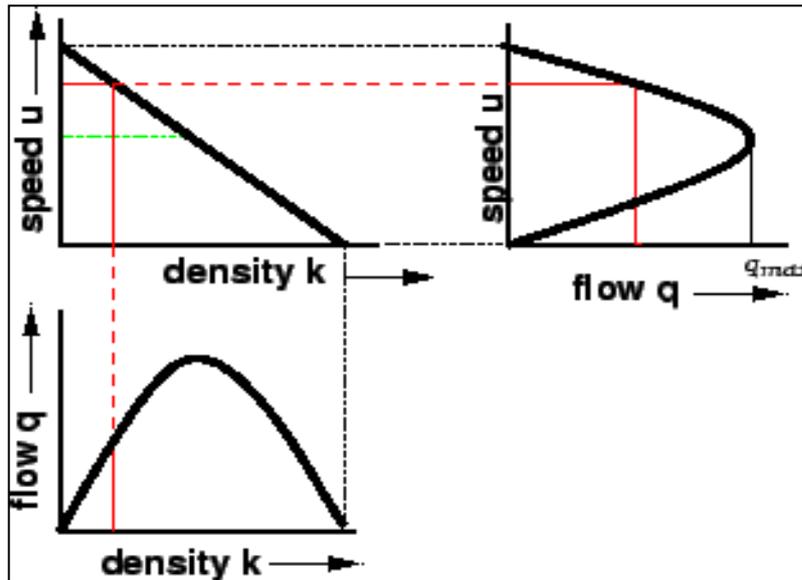
Figure 4.1 The relationships between the main basic road variables [160]

- When there are no cars in the facility, density is zero ($\rho = 0$), and flow is zero. Speed is purely theoretical for this condition and would be whatever the first driver would select, probably the highest possible value.

- When density becomes so high that all vehicles stop ($\upsilon = 0$), the flow q is also zero. This is because there is no movement and vehicles cannot pass a point on the roadway. The density at which all movement stops is called the jam density.

Flow is increasing (density as well) from zero while speed is starting to decrease which is equivalent to low and medium density and flow. Density still increases with a decline steadily in the speed before the capacity is achieved. Capacity can appear either in a high speed and low density or in low speed and high density. Moreover, there is a speed-flow-density diagram which interprets the interesting points on these diagrams aggregately.

4.1.2.2   Greenshield model

A real data observation leads to a modification of the basic formula, the early works carried by Greenshield and the equations below represent the potential of providing new results for the main road variables. The maximum flow can be obtained when:

$$\upsilon = \frac{1}{2}\upsilon_f \ldots \ldots \ldots \ldots (4.2)$$

Then, the maximum flow is:

$$q_{max} = \frac{1}{4}\rho_j v_f \dots \dots \dots \dots (4.3)$$

Where:

q_{max}: Maximum flow

ρ_j: Maximum density

v_f: Free speed

4.2   Modelling traffic flow

The traffic flow theory classified the traffic movement in the network into two main streams, interrupted and uninterrupted traffic flow. It is essential to understand them this helps to decide which models can be utilised. However, I will not go deeply to define them as they are explained adequately, we will determine the main parameters of each stream:

- **Uninterrupted flow:** can be defined as "All the flow regulated by vehicle-vehicle interactions and interactions between the vehicle and the roadway" such as the traffic in the highway.

- **Interrupted flow:** is defined as "All the flows regulated by an external means" such as traffic signal.

The fundamentals of traffic flow theory and its application to traffic simulation are [161]:

- Microscopic traffic modelling,

- Macroscopic traffic modelling,

- Mesoscopic traffic modelling.

There are a wide range of traffic approaches based on micro and macro simulation methods. The following provides a brief definition of each method. On the other hand, it has been understood that there is a considerable difference between the micro and macro simulation models in terms of supporting algorithms.

4.3   Traffic models methodology

The development of various theories concerning traffic flow has received considerable attention during the last decades; i.e. the theoretical, mathematical and simulation models.

The study of traffic flow began early in the 1930's with an application of probability theory [162]. Later, and after WWII, the increased demand for vehicle use and the expansion of the road system was the motivation for developing more researches into the traffic performance at highway and intersection systems.

The traditional methodologies (i.e. mathematical approaches and models) have been utilised largely and contributed significantly in presenting a valuable theoretical solution [101]. However, it has been stated that the effects of proposed ITS measures and disaster management system are difficult to be predicted and evaluated by using traffic flow theories [163]. This is because in such critical conditions, such as in disaster scenarios; there are critical considerations where the real time assumptions are changeable and the models are dependent on initial assumptions. The mathematical models generally have various limitations including the ability to replicate queues and delays for oversaturated conditions and a lack of comparison with observed field data [164]. In such problems, many researchers have decided to use the simulation models over other mathematical models due to the following:

1. The mathematical models are only applicable for undersaturated situations (in most cases).

2. The mathematical models do not take into account the very important factors/parameters, such as vehicle acceleration/deceleration and flow profile change.

3. Mathematical models are not applicable to model more than 2 links and 2 junctions (which make ineffective for disaster management on a wide area).

Later in the 1950's, the theoretical theory was developed with different approaches such as car-following traffic theory, further information can be studied (from for example [165], through [166], [167], [168] and [169] to [170]). Between 1959 and 1993, a series of seminars was held every 3 years with the aim of providing an overview of findings of the traffic flow theory, and the traffic flow theory here has begun take into account international assumptions [171]. In this study, we will define, illustrate and discuss the simulation models as it is our first step toward an efficient implementation of our contribution.

4.4 Simulation models for emergency response

Major disasters such as terrorist attacks and fatal earthquake incidents have caused huge damage to lives and economics, mostly in the disaster area. This damage could include transportation systems including road closure and traffic jams, and communication systems including the infrastructures.

Models become very important for the development and evaluation of a broad range of road traffic management and traffic control systems. The simulation models are used to mimic the interaction between the vehicles at a specific time and each traffic model has its unique characteristics. The models represent various relations among drivers within traffic network systems.

Various traffic simulation models are used to simulate the traffic flow in an urban network in such scenarios, and the simulation model; where applied, have offered significant results while being used to demonstrate the effectiveness of schemes for a range of objectives. Consequently, we select the simulation models to represent our study for the following reasons:

- Many researches have reported that the Modelling & Simulation (M&S) based approach is the most suitable method to develop the solution for the problems in real-world complex systems [101].

- Moreover, these models are capable of solving the complicated problems that cannot be solved by traditional tools; these problems can be congestion and incident management, etc.

- In addition, simulation models have been considered the best solution for studying the factors that affect capacity rather than using field data because of the difficulty of controlling these factors on site and getting the same factors for different geometric designs. Their role in facilitating the traffic evaluation processes is significant.

- Suggesting solutions and recommending alternative scenarios without expensive resources which are necessary to implement alternative strategies in the field can be done by such models [172].

4.4.1 Mesoscopic simulation models

Mesoscopic models consist of microscopic and macroscopic approaches to provide a high efficiency describing all key characteristics of the road. For example, if the drivers decide to change lanes, this is a microscopic aspect, while this decision should depend on the densities and speeds which are obtained from a macroscopic model.

4.4.2 Macro-simulation models

Macro-simulation models (Also termed Macroscopic) or (traditional transport models) are defined as "Providing an aggregated representation of demand, typically expressed in terms of total flows per hour" [173]. In other words, they deal with characteristics of the section of any road. Such models could be traffic engineering tools and transport planning tools, such as TRANSYT and OmniTRANS software. Macro-simulation models based on the continuum traffic flow theory; traffic flow theory is the description of the time-space evaluation of the variables; volume, speed and density [161] .

Macroscopic models are considered not computationally expensive. Despite the fact that large amount of data related to the network are required to be analysed, the simulation can be acceptable but may not be utilised in such huge and complex problems. In other words, macroscopic simulations fail to adapt to random and rapid changes in the environment [174]. Consequently, long sections, hundreds of miles, require high numbers of computation processes which cause increasing in time simulation, while microscopic and mesoscopic models were suggested to fit to simulate such traffic networks [172].

4.4.2.1 OmniTRANS software

OmniTRANS is an Integrated Multi-Modal Transportation Planning Package; it is an example of macroscopic vehicle modelling package. The main purposes of this software are:

- Project management information (which describes how the data are structured)

- Describe the data (networks, matrices, zones data etc.)

- Users defined selections of data (for example, describing city network variables, network links, and urban/suburban areas)

- Users defined specifications for reports and output plots

Typically, the software contains many templates, static assignment, dynamic assignment and transit assignment. This templates diversity helps the simulator to obtain different information. Furthermore, the project templates also contain common definitions, useful specifications and lists etc., that are passed from project to project.

The OmniTRANS software is a transportation oriented program which mainly deals with assigning traffic volumes into the available transportation network. The software is considered as a macroscopic approach which deals with the traffic volumes as a whole traffic and not a distinct vehicle. The major characteristics of the software are as follows:

- The software uses several transportation modes, like private vehicle, busses, light rail, motorcycle and bicycles.

- The transportation network links could be customized according to the actual status in the city network.

- The transportation network geometry is to be set according to the background satellite image of the city with an adequate scale.

- The nodes, links, and centroids of the transportation network are coded.

- The O-D matrix is set according to previous data.

- The software implementation subroutine language called RUBY to conduct various jobs that contains the models used in the software, such as static, dynamic models etc.

The important entry data sets that are required within the dynamic modelling will be defined below, these input files could be grouped into the following categories:

1. The purpose of the trips should be defined; land use in the area to extract the O-D Matrix, these could be divided into

   - Work
   - Home
   - Others

2. The type of transit transportation, the mode of the travel which could be divided into

   - Roadway vehicle
   - Bicycle
   - Public transport (light rail train, bus, train and tram)
   - Walk

3. Time of the trips along the daytime

4. The user type of the analysis (internal cordon, external cordon, through traffic from certain origin to certain destination)

5. The type of the assignment (all or nothing: which means that all the demand vehicles go through certain links neglecting the link capacity, capacity constraints models, through selected links or areas)

6. Types of the constrains (costs, distance, time, waiting time, penalties, fares, number of passengers)

7. The iteration value

8. The transportation network geometry (link type) from freeways to major roads including rail, bus, bicycle, walk ways, and capacity.

9. Traffic facilities and projects like the intersections, roundabouts, tunnels and bridges.

10. The socioeconomic data in the area that to be entered in the O-D matrix.

11. The trip attractions and trip productions points.

12. Any counters and screen lines in the transportation network.

Below, we will describe the running steps:

- First, downloading the OmniTRANS software is a top priority.

- Then, the user can simply draw the components of the network; these components are defined. The input data to the software includes the link characteristics, such as link length, road capacity, road layout, speed, the vehicles type, link type, the free speed and the design speed

- The O-D trip generation matrix for certain time of the day is applied at this stage.

- Then, the maximum capacity for the network should be determined.

- After that, a specific job is to be written using the software language. However, it should be noted that the above program is limited to only 25 zones. To overcome the OmniTRANS limitation, a model was developed; called NETRASOFT. The most of the main functions (except the visualization and network map user interface) in the OmniTRANS package can be carried out by NETRASOFT [175]. This latter software has considered the Lighthill - Whitham - Richards (LWR) model. Although, the development new package has the ability to analyse for unlimited network size, still there is a difference between the two software programs above. The main difference is the calculation of the travel time [175].

In summary, the geometric traffic data represented by O-D matrix has to be collected, then the population data. Subsequently, the O-D matrix will be dispatched into the transportation network, assuming no accident happened. Then, after the incident attack, a new O-D matrix shall be generated for the purpose to guide people to the safe area. A dynamic scheme is applied and a snapshot is taken every 10 -15 minutes (the implementation details will be discussed in Chapter 6).

The people's response time to the event is taken and the average vehicle occupancy is considered (see Section 6.4). Finally, the total time for the evacuation process is calculated (the VANETs technology with the aid of virtual cloud infrastructure is employed here to increase the potential of minimizing the total evacuation time and hence increase the opportunity to receive/send the emergency messages between the drivers and the control management unit).

4.4.3   Micro-simulation models

Micro-simulation models (also named Microscopic) are defined as "Micro-simulation models have the ability to model each individual vehicle behaviour within a network. In theory, such models provide a better, and 'purer', representation of actual driver behaviour and network performance" [173] and [176].

Another reference has defined the micro-simulation models as "They are a powerful communications tool because they are able to present its outputs as a real-time visual display" [177]. It describes the interaction among drivers, vehicles and roadway environment [178]. This implies modelling the actions, e.g. acceleration and decelerations and lane changes, of each driver in response to the traffic conditions [161].

These models deal with an individual vehicle movement within the traffic system, its travel time, speed, and how the driver is moving.

The potential of microscopic models is they are able to exercise power on the individual vehicles movements in the traffic stream as they consider car-following models [68].

Historically, few examples of micro-simulation in regional evacuation analysis are reviewed due to difficulties of modelling the movement and interaction of a large number of autonomous vehicles. This is because of computational burden. In recent years, this limitations have been greatly decreased (if not eliminated) by increases in computational power and advancements in software engineering [179].

Microscopic models have a wide range of advantages. We summarized them in bullets below:

- Micro-simulation models are very useful where the increasing system complexity and uncertainty can be involved in the operation of the urban traffic networks. However, the concern is often expressed regarding misuse of micro-simulation. The response to a survey of micro-simulation model users was summarized as "*Micro-simulation is useful but dangerous*" [180].

- Many important factors are considered to extend the use of traffic micro simulation models, illustrate the transport network and their operation in significant detail.

- The microscopic models are based on some traffic factors which have the ability to manage the movement of individual vehicles in a transport network. High level of powerful graphics offered by most software packages that show individual vehicles traversing networks which include a variety of road categories and junction types [173].

- It has been reported that they are extremely useful tools which could be the next generation of traffic models, and could provide the environmental for discussion for many interested people [181] and [180].

- Nowadays, reasonable low cost and high performance computers enable micro-simulation systems to directly model all the components within traffic systems, [181].

- Furthermore, microscopic simulation models are able to evaluate various traffic management alternatives in order to determine the optimum solution for any traffic scenario and provision of visualization for the case under study [182].

- In reality, traffic data is rarely constant and repeatable, so many reliable suggestions can be offered for different traffic problems such as congestions, incident management etc. which cannot be solved by applying the traditional tools because of their sophisticated transport system [183].

- The models are capable of presenting different evacuation scenarios, the advantage of using simulation – based models is the ability to observe the evacuation plan. Also, they have a wide range of advantages including indication the congestion points and the ability to reduce the computational effort [184].

- And finally, It has been reported that micro-simulation models, such as S-Paramics, are recommended for evaluating various incident management techniques without affecting real road users [132].

4.4.3.1 S-Paramics and its features

S-Paramics (PARAllel MICroscopic Simulation) is good example of the psychophysical models. It is a microscopic vehicle modelling package, available widely and the UK's most used to assess the traffic components performance. The S-Paramics is a micro-simulation software package which is simply defined as "A powerful communications tool because it is able to present its outputs as a real-time visual display" [177].

Historically, S-Paramics has been introduced to be used in an emergency evacuation area since 2002. Church and Sexton have employed S-Paramics to obtain the clearing time estimates under different evacuation scenarios. Various input data have been adopted such as different combinations of demand level, normal traffic and traffic control [184].

It has been concluded that the S-Paramics is a software system that could simulate the individual components of traffic flow and congestion and presents its output as a real-time visual display for traffic management and road network design [185].

Also, it has been noted that it is one of the new generation of desktop micro-simulation models which has emerged which helps effectively in modelling the evacuation [179]. Thereby, S-Paramics model is characterized as offering the real-time assessment, called dynamic feedback [186] where it shows the driver behaviour within the simulation model.

In other words, S-Paramics represents the actions and interactions of individual vehicles as they travel through a road network and models the detailed physical traffic road. As a consequence, S-Paramics can portray and evaluate the variable circumstances which lead to congestion in all types and sizes of road network [177].

It has been concluded that S-Paramics simulation models provide the ability of modelling individual vehicles in high details, and able to provide various traffic information; such as flow and delay. It's used widely in traffic problem such as congestion by simulating the interaction between the road components and the Intelligent Transportation Systems [164].

An ability to interface to other common macroscopic data formats and real-time traffic input data sources [181] . In addition, the Interfaces from S-Paramics to ITS and Urban Traffic Control Systems enable simulation models to be used to develop control strategies for incident and event management and to investigate options for optimizing adaptive signals, and urban or motorway control systems. Figure 4.2 below shows an example of this [177].

Figure 4.2 Example of S-Paramics [177]

The simulator can model around 200,000 vehicles on around 7,000 roads (taken from real road traffic network data) at faster like 'real-time' rates, large models may extend to hundreds of square kilometres. It is traffic simulation software that is capable of designing and analysing various traffic networks such as complex intersections, merging sections and roundabouts [187] and [177].

Also, S-Paramics is able to model a big city network which requires a large amount of input data. In case of having huge statistical data, S-Paramics is able to simulate in very high speed batch mode operation in addition to its visualized real time environment [181].

SIAS's system, S-Paramics, includes multi models such as car-following lane-changing models, dynamic and intelligent routing.

Various major traffic network data can be analysed and calculated accurately by S-Paramics including the speed, density, flow and delay. So far, no automatic real world system, comprehensive model or even a human could be as precise as demanded. Some of the other advantages of S-Paramics include:

- Easy data entry through a user-friendly interface

- Ability to create evacuation zones

- Ability to create, modify and delete some traffic layouts, such as intersections and roundabouts

- Another important feature of S-Paramics, the component of S-Paramics comprises the main parallel computational element which has the potential to move vehicles around the road network as realistically as possible, taking account of other vehicles, crossing priorities, traffic lights, safe distances and so on [187].

4.5   Simulation models limitation

Simulation-based models function as a "what if" methodology and can be used to evaluate a set of pre-specified candidate plans, and several versions of micro-simulation have been developed and released to improve the efficiency of the traffic network and to scale the potential of addressing solutions[188].

However, a few shortcomings have been reported, this report will state some of the most important weaknesses which need to be addressed.

- Compared to more conventional models, it is important to realize that there is extra cost involved in micro simulation models [173].

- Pedestrians are a vital element in transportation systems. Nevertheless, the pedestrian models are not represented efficiently yet except for some attentions to the pedestrian effect on the vehicle movement [176].

- Finally, the traffic simulation models are complex and make large demands on computer time; it means they require extensive inputs and long execution times [151].

- These limitations have limited effect on our proposed model.

4.6   Simulation language

Most simulation models contain their own control language to execute various computational tasks.

Most contemporary simulation packages are written in general or high level languages such as Fortran [181]. Fortran language contains various subroutines, which encapsulate the functions of the user needs [175]. Also, the code of the algorithms has been written by using the Compact Visual Fortran (Version 6.5), this version is capable of presenting a new generation of using visualization with different output screens much better than the old version [164]. The advantage of visual micro-simulation systems is that they cannot hide errors, while other systems seem good at concealing them [181].

For S-Paramics, it has been established using C*, which can be defined as "C* (pronounced "sea-star"). It is an extension of the C programming language designed to help users program massively. In addition, "It is a concise and efficient language for programming many other architectures" [189].

4.7   Evacuation simulation based models

The evacuation management is considered a complex problem as comprises many problems arise during the evacuation process [68]. In such problems, the clearance time in a residential neighbourhood; evacuation time is crucial to be estimated [186].

In support of disaster management in a network environment analysis, more than 20 different evacuation approaches; computer based, are developed to describe and analysis these problems, currently most common form of the approaches are simulation, optimization and risk assessment methods [190].

To prepare the suitable models for unexpected disaster, the computational efficiency of a mode is significantly crucial to generate the solutions/alternatives and then to propagate the decision. Therefore, simulation has been the preferred tool of choice [152].

In order to demonstrate these approaches, static and dynamic data related to network need to be considered in these techniques including origin-destination assignment, modes of transportation, capacities and the response time of the evacuees [174]. Further details involving the techniques can be found in [190] and [191].

To reduce people's vulnerability to various disasters, various evacuation strategies are developed and improved to control and relieve the chaos situations which aim to evacuate the threatened people.

The effective and efficient evacuation strategies mainly depend on several activities which should be considered, one important component of this is the cooperation between the transportation and communication systems, and the traffic behaviour characteristics.

In the case of emergency, manmade and natural disasters, and the evacuation strategies are emphasized to be implemented. Small scale evacuation deals with people evacuation from small areas such as buildings, while large scale evacuation, the case that we emphasis in this study, may include small evacuation scales. For example, the neighbourhood evacuation scale is most appropriate in this as wildfires involve local small-scale evacuations.

In the case of large scale evacuations, known as mass evacuations, once the notification of various evacuations is given, the evacuation leverage can be assessed by the total time needed to evacuate the same number of people/vehicles from the affected area, and/or by the increased number of vehicles that can be avoided from approaching into disaster zone. To this end, most of the proposed approaches are based on M&S. As a part of this study, the aim is at improving the evacuation strategies performance in terms of:

- Increasing the number of vehicles leaving towards pre-determined safe area/emergency zones.

- The potential of increasing the usage of the transportation sources

The above aspects coincide with some other important elements such us the trip generation and destination, evacuation start and end time and the challenges between various employing different strategies in the same scenario.

It has been noticed that simulation modelling, especially for large scale evacuations, has attracted most organizations and modellers over the last two decades considering many different large hazards [179]. However, no efforts had been conducted in the area of evacuation trip generation modelling by the early 1990's [68].

Therefore, in this study, an essential classification are presented early based on the approach applied in the evacuation models, namely simulation - based models. Meanwhile, a sub-classification of the simulation models can be applied. They have been classified into two categories; general and specific traffic flow models [184] and [186].

The general models have been developed in general purpose simulation models such as THOREAU. While, in such specific evacuation models, the core issue in these models is how to introduce the route selection which compromises the driver safety; the drivers either select the least congested routs, or follow the roads that have been selected by the decision makers [186].

4.7.1 Pre & post evacuation models

A number of programs are being implemented for different evacuation plans, and each evacuation approach selection depends on an unique method which can be produced according to different situation circumstances.

For pre-evacuation and post-evacuation stages, some traffic experts have selected the tools which are developed for general purpose and adapt them to evacuation conditions. While others preferred to select specific programs which are developed for an evacuation scenario.

In 2008, a comparison of 30 traffic computer programs based simulation models was conducted by Hardy and Wundelich. The comparison was based on the complexity of the system. Additionally, the study addressed the difference between the three simulation classes; Micro, Macro and Meso-simulation models [157], additional information about the models can be found in [10].

A few examples for each simulation model have been reviewed in the next sections; Sections between 4.7.1.1 to 4.7.1.1. However, the definitions of some simulation models and their classification in three levels have been presented previously.

4.7.1.1   Meso-scale models

An evacuation model has been developed, called DYNEV. It is a meso-scopic model developed by KLD associates [151] and [192]. However, it is based on the movements of platoons of vehicles rather than individual vehicles [152].

4.7.1.2   Macro-scale models

Some macro-level models have been developed to be used to support the real time evacuation decision makers, such as NETVACI, MASSVAC and CLEAR. The ability to supply the transportation information during the evacuation management is the reason for using these tools [157] .

In late 1970 and early 1980, a number of simulation models were developed to assess and address traffic emergency plans. In 1982, Youssef Sheffi et al., from MIT, developed the NETwork emergency eVACuation model (NETVACI) that addressed the estimation of clearance times, that is the time until the last vehicle or evacuee leaves the affected area, for areas surrounding nuclear power plants [151] and [184], it is a fixed-time macro-simulation model. This model used the traffic flow models available to simulate the evacuation process, which means the clearance time also, the model was able to calculate the total evacuation time until the evacuee reached the safe area. In this model, NETVACI works on assumption that the drivers select their route according to their prior network knowledge, called "myopic" which means drivers will assess the traffic ahead.

The advantage of this model is the potential of simulating a large traffic network at modest computational costs. And, it has overcome the NETSIM micro-simulation model drawbacks [193], [188] and [194]. However, a few limitations have been reported regarding the use of NETVACI model, such as it is a deterministic rather than dynamic model. It did not make assumptions about evacuees' behaviour [184]. A limitation in applicability to hurricane evacuation is found. Also, the behaviour of drivers during the evacuation has not been considered [68].

MASSVAC is also a macro-simulation model which has been developed to apply to hurricane evacuations [195]. For the major road arteries, the MASSVAC macroscopic model is capable of estimating the evacuation time under different traffic and disaster severity conditions. The model drawback involves ignoring the time taken to reach the nearest major arterial road which affects the evacuation estimation time.

A macroscopic evacuation called CLEAR (Calculating Logical Evacuation And Response) model has been developed by KLD Associates [151]. This model was developed for the evacuation in the event of specific hazards, for nuclear regulatory commission, which require to set the model by considering the vehicle movement only along primary arteries, thereby reducing the computational burden [185].

It estimates the time required for clearing a certain disaster area for a specific population density and population distribution by simulating the movement of vehicles on a transportation network according to the conditions and consequences of traffic flow. The program also models the distribution of times required by individuals to prepare for an evacuation [151].

Other simulation models have been developed to be used particularly in emergency situations; such as EVACD and ETIS, for further information; see [196] and [197].

4.7.1.3 Micro-scale models

Traffic simulation techniques have been used since the early days of the development of traffic theory which provide the potential of positive usage of micro-simulation models to the analysis of complex traffic problems.

More recently, evacuation analysis requires a relatively fine level of traffic network details. First, many evacuation studies are employed for day-to-day traffic applications. The incident management system can be difficult to be evaluated using normal traffic theory as it requires more details regarding the situation whether it is dynamic, stochastic and most importantly is the driver behaviour.

For example, NETSIM is the earliest microscopic model, highway traffic simulation model. The model has been developed by KLD Associates, which is used for network researches as well as for evacuation planning [14], [15] and [179]. The model addressed the simulation of the traffic system of small urban networks under normal operating conditions, the model can handle 99 nodes and not more than 160 links and the maximum network occupancy does not exceed 1600 vehicles. In early 1980, the first use has been recorded by HMM Associates to estimate evacuation time for a nuclear plant area. However, its drawbacks include its capacity limitation to deal with large networks, and deficiency of dynamic route choice models [194].

Another drawback was reported by Yosef Sheffi [193], even for very small network implementation, the computational costs exceed tens of thousands of dollars. Furthermore, the modellers should specify the intersection turning movement which does not involve the dynamic route selection.

Hobeika et al. have developed and improved a mass evacuation computer program called MASSVAC, they developed MASSVAC 3.0 and upgraded it to MASSVAC 4.0. The model has been developed specifically to deal with incidents at nuclear power plants. The evacuation plan suggested evacuating people can be done in two phases, the first stage is that people evacuated from the a disaster area should be enabled to choose the shortest routes and then be directed to a safe area in the second phase, further information reported in [198] [199], [186], [195] and [200].

Another micro simulation model has been produced to analyse a large scale evacuation, called TEVACS [201]. The natural design of a transportation system is a combination of various traffic modes such as automobile, public transportation, motorcycles and bicycles that should be included in any model to address the problem effectively. In this model, each transportation mode has been treated as a universal unit called the PCU; Passenger Car Unit [186] & [201].

Some general traffic software packages are used also for the evacuation conditions; such as S-Paramics and VISSIM [14] & [24]. S-Paramics has been used also in emergency evacuation. They applied S-Paramics to obtain the clearing time estimates under various scenarios [186] and [184]. In 2008, VISSIM models were used to find the locations for access to the reversal flow lanes (contraflow) from normal flow lanes [202] and [184]. Liu et al. have used VISSIM as the online-simulation module of the proposed integrated emergency evacuation system [203] & [184].

In 1991, Southworth reported that a wide range of micro-simulation models addressed some of the critical problems at intersections such as delays, where the majority of delays occurred. Route choice is generally either myopic (drivers select the least congested link at each intersection) or restricted, drivers wandered aimlessly through the unknown streets as a result of emergency managers controlling the flow at each intersection. They have been used primarily in geographically limited urban network studies (for example, primary roads only), or in relatively small urban and rural area studies [185].

CORSIM and DYNASMART are also used in evacuation modelling, additional information has been produced at [204], [205], [206] and [184].

4.8 Data collection

In urban networks, the considerable traffic information which is required to be available, depends on the characteristics of roads, behaviour of the drivers and the interaction between them, and this has significantly attracted many stakeholders. Collection of real data from different cities are used as an input data for the simulation models and then enables us to present the important factors that mimic the behaviour of the traffic components.

End users were involved in the data collection by providing the necessary statistics in data related traffic and basis structure of the town involved. Also, most of the data are available in public domain. A real data for many cities have been provided: two cities are located in the Middle-East, called Al-Ramadi and Al-Husenya. In addition, a city is located in the UK, called city X (for high confidentiality and security, it is not allowed to mention the city name; there is an agreement between Salford University and the Council of the city in the UK).

It is logical to expect the presence of many different variables affecting the behaviour of the traffic, particularly under various conditions during and after the serious risks. To understand and evaluate the disaster management system performance, we will study the implementation of the disaster management system on different traffic city conditions, different disaster scales, and different scenarios with collaboration of various information and communication technologies (ICT). Also, many traffic variables are demonstrated in this research, such as volume, flow, time setting, speed and geometric design. Normally, just to mention, there are different tools and methods can be utilised to collect the data depending on some factors such as the availability of the tools, accuracy, the city culture and environment. The information could be collected through manual recording, video recording, and loop detectors.

To cover the most important issues, several cities sites are selected, so nothing not exist can be ensured. The cities have different characteristics; such as desired speed and components, variation in the population, different sizes.

The simulation model is considered a very useful model, however, there are few challenges and limitations. One limitation is the validation and calibration of various parameters and results of the system modelling.

Calibration is "A process of adjusting parameters used in the model to simulate the road performance", while validation can be defined as "Accomplished by comparing traffic volumes estimated by the model to actual base year ground counts" [177] and [207].

Various parameters may be adjusted until the model satisfactorily replicates the ground counts [171]. Once calibration is completed, the model is used to assess the performance of the existing traffic system. Traffic variables, estimated by the model, are typically compared with actual traffic counts at points.

These challenges are complicated as the traffic network behaviour would vary depending on some factors such as disaster scale, evacuation scale, and network scale, and many other factors. Also as this report is looking at such a big event with disaster evacuation, then the small differences between a calibrated base model and an uncalibrated model are likely to be small.

In normal scenarios and many other traffic network minor problems, it has been noted that validation level cannot be underestimated, however it is concluded that necessary validation is out of reach for evacuation researchers [185].

In evacuation status, it is logically difficult to collect the traffic data as the chaos situation is prevailing during disaster, and hence calibration is not possible for an evacuation event [186]. Consequently, a micro-simulation model can be used under certain conditions to estimate the clearing time; the other conditions such as driver behaviour under possible panic situation.

Meanwhile, in our problem, simulating the traffic network evacuation which deals with mass evacuation procedures, considers very difficult to have experiment result; it is almost impossible to have real evacuation operation results, to be compared with our simulation results and hence evaluate the simulation models performance.

The sensitivity to this can be tested by running the scenario with variations in the base demand, say add or subtract 1-5 % of the traffic demand of the tested cities, and very little difference has been found . Also, in case of such an extended project, it has been assumed it is not of paramount importance to spend lot of time on calibration of the base model as the aim is really looking at the differences between strategies and the start point would not be too critical.

Each city splits up into different districts and boroughs, and each city map consists of different number of zones, nodes and links. We will discuss the network components in the next section.

4.9   Network data

The aim of this section is to summarize the details of the selected sites such as location maps, layouts, collected data, etc. The data was also used to provide the necessary input for developing, evaluating the simulation models and comparing the results.

The roadways, represented as links in city map, may have two functions: they provide mobility and access. From a design perspective, these functions can be incompatible since high or continuous speeds are desirable for mobility, while low speeds are more desirable for land access [175].

Each node-to-node connection is a directional link and typically there are two directions for each road. Also, each node represents different characteristics, such as the type of traffic control.

Each road has an associated type which gives information on attributes like the number of lanes; such types are the arterials which emphasize a high level of mobility, while the local facilities emphasize the land access function, and finally the collectors offer a balance of both functions. Links carry the characteristics of traffic and geometric design (e.g. speed, visibility, number of lanes, directional movement, etc.).

Other available data for S-Paramics is the zones which can be defined as any given link in the network graph to any of several destinations. To get people to travel into/from city, we need to create zones and each zone could be one of three main zones classification; Residential, Commercial and Industrial, as shown in Figure 4.3 [177].
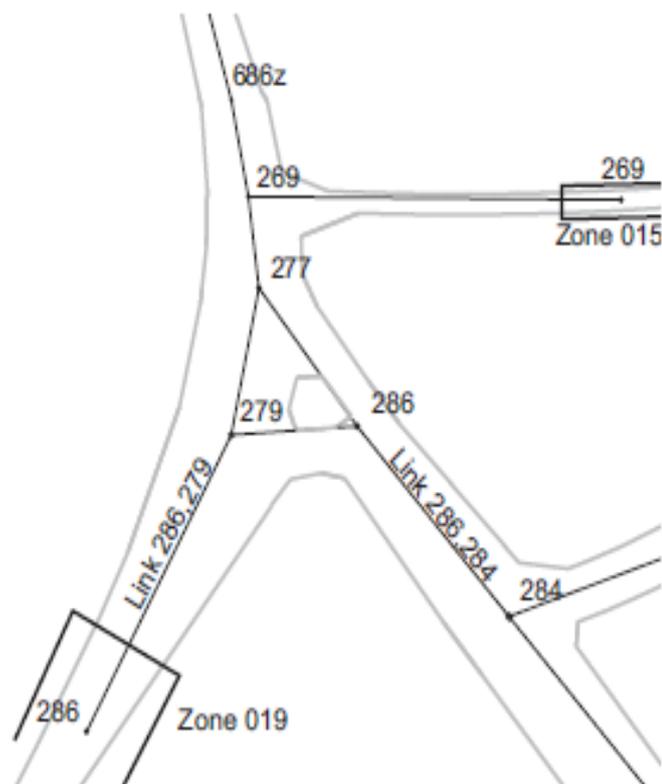
Figure 4.3 Links, nodes and zones [177]

4.9.1   City data extraction

Various packages of data have been provided from different cities, such as speed, flow, capacity geometric design; lane length and width, no. of lane and traffic light phases etc.

4.9.2   Al-Ramadi city

Al-Ramadi city lies in the West of Iraq; it is the centre of Al-Anbar governorate, on the Euphrates River, northwest of Habbaniyah Lake, see Figure 4.4. The Euphrates river passes at the upper limit of the city, whereas, Al-Warrar channel divides the city into two parts. There is an absence of mass transit systems, which results in the large use of single occupancy vehicles for personal movement.

The topography of Al Ramadi is generally characterized by relatively gentle slopes. The danger of floods forced the city growth away from the Euphrates River in the north in the direction of the highway towards the south [208]. The city is divided into five traffic analysis zones (TAZ), these zones are shown in Figure 4.4.

The Iraqi Censuses have reported that Al-Ramadi city has witnessed many patterns of growth during the past decades. The population of Al-Ramadi city has grown from 9919 in 1947 to 163,206 in 1997. In 2000, the population increased dramatically, depending on the latest survey indexes, Iraqi Census report has written that Al-Ramadi population is estimated to be approximately 230,500 people in 2010 [209]. Considerable data are available for Al-Ramadi city; the essential information which is used for the operations are summarized in Table 4.1:

Table 4.1 Al-Ramadi basic data

Measurement	Value
Population of the city, people	230,500
No. of zones	5
No. of evacuation area	2
Average no. of people per vehicle	4

Figure 4.4 The transportation network of the Al-Ramadi city

4.9.3   Al-Huseneya city

Al-Huseneya city is a major district in the Karbala governorate, and is situated 15 km to north east of Karbala city, and 70 km at the south of Baghdad city, the capital of Iraq. Some of the population of Al-Huseneya is rural, according to the 2007 censuses [210]. The overall population of Al-Huseneya is estimated around 125,000 capita.

Figure 4.5 shows the transportation network map of Al-Huseneya city, the network consists of some zones, nodes, and links. The city is divided into 2 zones, see Table 4.2. Zone 1 is on the west side of the major street which divides the city into two parts. The east part of the city contains Zone 2 which represents the old city centre that attracts high number of trips in the morning peak hour. The surrounding areas around the city are major agriculture areas and the connections of roadways in these areas are very poor. It is important here to present the essential information for the evacuation operation of Al-Huseneya city; they are summarized in Table 4.2.

Table 4.2 Al-Huseneya basic data

Measurement	Value
Population of the city, people	125,000
No. of zones	2
No. of evacuation area	1
Average no. of people per vehicle	5

Note also in Figure 4.5 the evacuation area. Its purpose is to provide an appropriate and safe location for the population in case a major disaster strikes the city and people need to be moved out of the city. The evacuation zone was chosen in the south of the city, because there is a direct roadway that joins the evacuation zone with Karbala city, the capital of Karbala Governorate. If there is a need to give medical supplies or transport to the injured and affected population, it will be best provided through the local roadway to Karbala city, the local street leads to a nearby Karbala city about 15 km away.
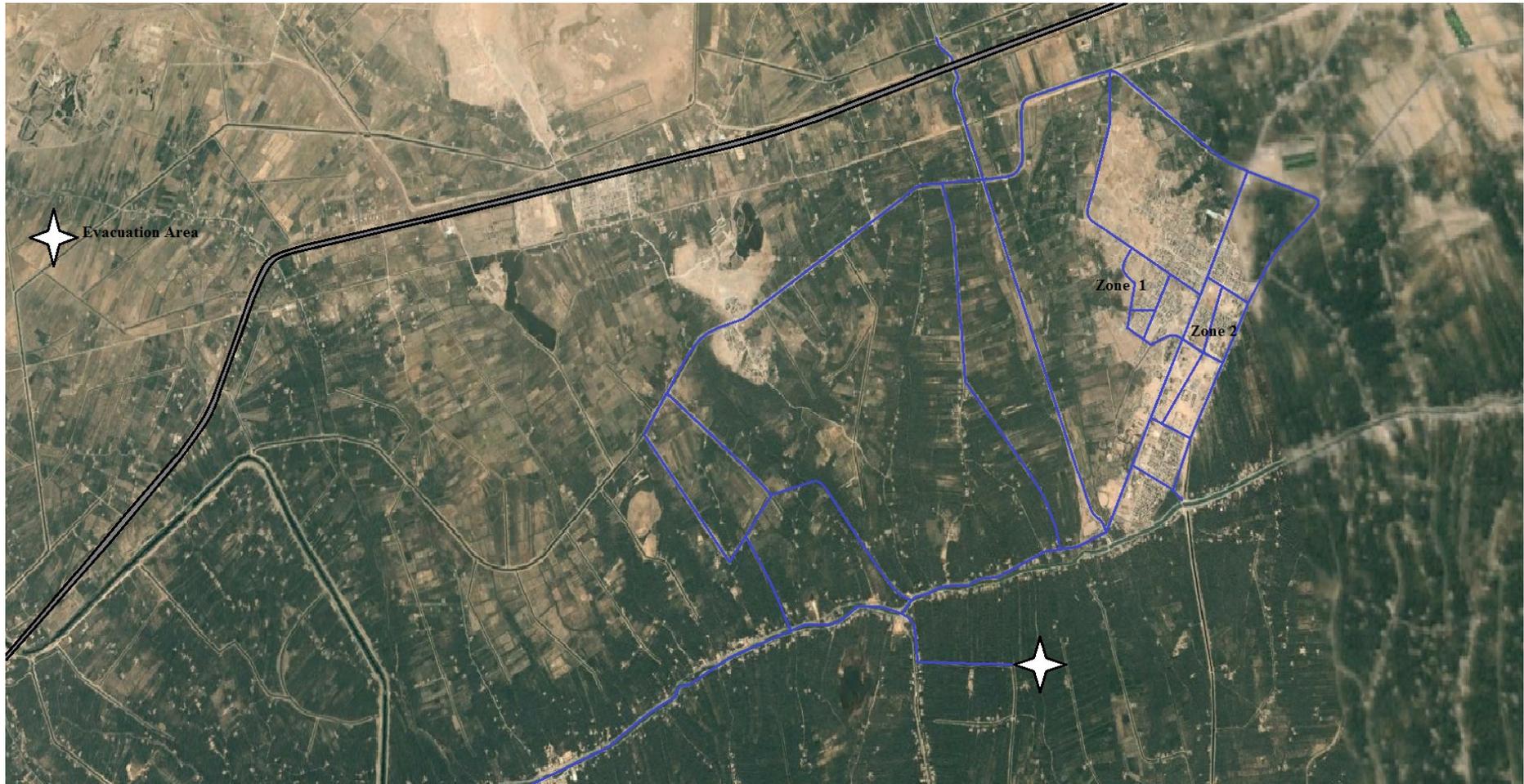
Figure 4.5 The transportation network of the Al-Huseneya city

4.9.4   City X

It is a city in England, in the middle of the UK, and forms one of the main urban areas within the UK. The 2001 census showed that at 2012, the Office of National Statistics estimates the population around 170,000 people.

In this study, we will refer several times to evacuation studies conducted in this city and due to the sensitive nature of the subject we cannot identify the city by name.

Table 4.3 City X basic data

Measurement	Value
Population of the city, people	170,000
No. of zones	26
No. of evacuation area	3
Average no. of people per vehicle	1.5 - 2
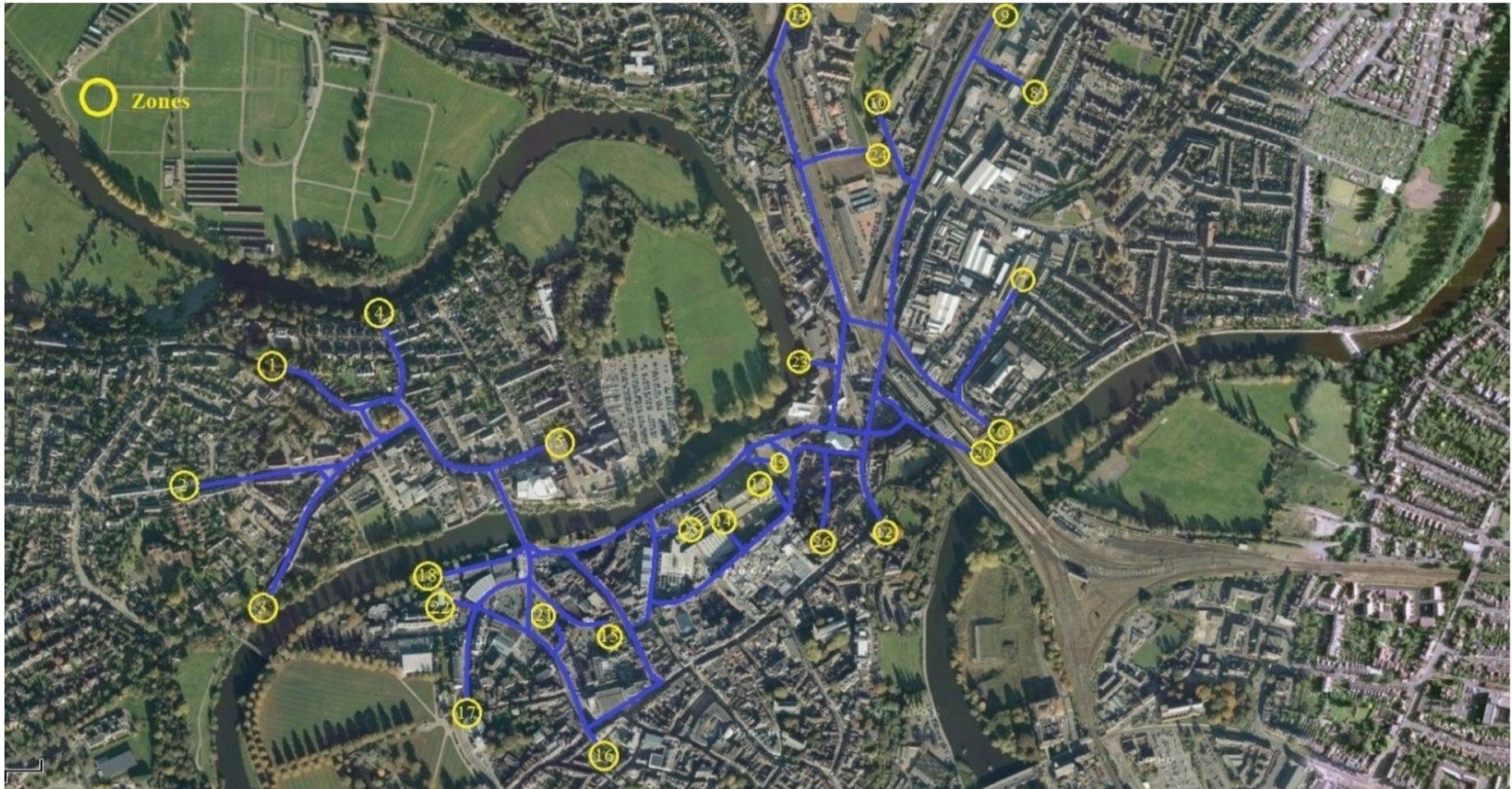
Figure 4.6 The transportation network of the city X

PROPOSED SYSTEM: DESIGN AND ARCHITECTURE

The current chapter describes the design and architecture of our proposed Intelligent Disaster Management System. This system is developed to be adapted in urban environments. For this implementation, a macro-simulation technique has been selected to produce and compare the computing results because of its ability in such a disaster situation. A reasonable cause for this selection is made in Chapter 4. The OmniTRANS transport software is selected to perform the system development and performance, Section 4.4.2.1. The system model is improved by means of introducing a novel message propagation algorithm through VANETs, and the effectiveness of the system was validated by means of extended simulation results.

This chapter is organized as follows: Section 5.1 describes the architecture and its various components of our intelligent disaster management system. Section 5.1.1 explains the intelligence layer of our system. Finally, Section 5.3 introduces a novel message propagation algorithm.

5.1   System Architecture

Our research is concerned with developing a disaster management system for disasters of various scales with a focus on transportation systems which exploit ICT developments. The Intelligent Transportation Systems (ITS) have been employed including VANETs (Vehicular Ad hoc Networks), mobile and Cloud computing technologies to propose an Intelligent Disaster Management System.

Figure 5.1 depicts the proposed architecture of the Cloud - enabled Vehicular Disaster Management System. The system consists of three main layers. The Cloud Infrastructure Layer, as a service layer, provides the base platform and environment for the intelligent disaster management system. The Intelligence Layer provides the necessary computational models and algorithm in order to devise optimum emergency response strategies by processing of the data available through various sources.

The System Interface Layer acquires data from various gateways including the Internet, mobile smart phones, social networks, transport infrastructure such as roadside masts etc. As depicted in Figure 5.1, vehicles interact with the gateways through Car to Car (C2C) or Car to Infrastructure (C2I) communication.

For example, vehicles may communicate directly with a gateway through Internet if the Internet access is available. A vehicle may communicate with other vehicles, road masts, or other transport infrastructure through point – to - point, broadcast or multi - hop communications.
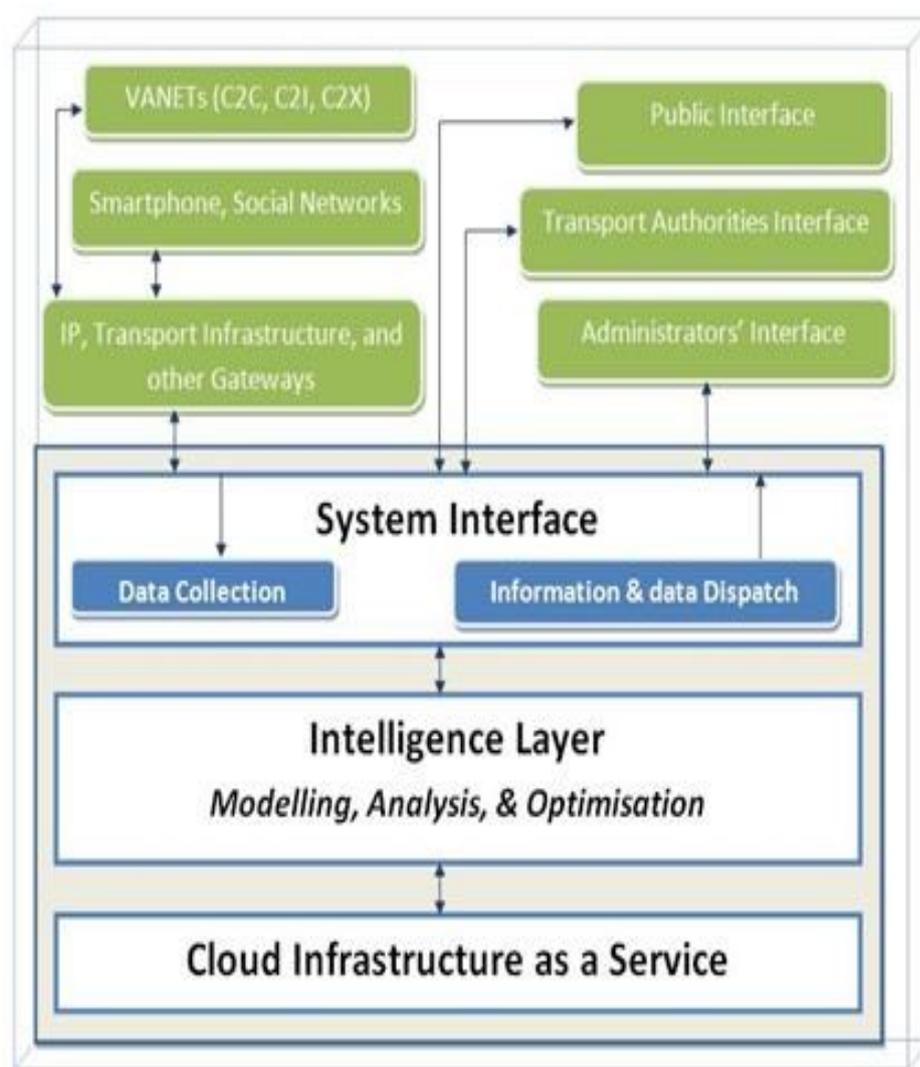
Figure 5.1 Intelligent Disaster Management System – Proposed Architecture

The disaster management system provides multiple portals or interfaces for users to communicate with the system. The Public Interface allows any individual to interact with the system. The purpose is to interact with the system on one – to - one or group/organization basis with the system, either to request or provide some information.

Of course, an authentication, authorization and accounting system is expected to be in place to allow and control various activities and functions. The Transport Authorities Interface provides a high - privilege interface for the transport authorities to effectively manipulate the system for day to day operational management. The Administrators' Interface provides the highest privilege among the system users and is designed for policy makers and strategists to enable the highest level system configuration.

The motivation and background for a Cloud-based distributed control system can be found in some works, for example in [211], where the authors presented an architecture for distributed virtualization using the Xen hypervisor; it allows control and management of a distributed system by posting high - level queries on the system and their validation through real-time monitoring and control of the system. Monitoring relates to the acquisition of data and control relates to dispatch of commands and decisions. Also see [212], where a Pervasive Cloud is proposed using the WiMAX broadband technology for railway infrastructure. A useful description of cloud computing usages is provided in Section 2.6.

5.1.1   The Intelligence Layer

The architecture of our proposed emergency response system has been described in Section 5.1. The details of the Intelligence Layer will be given in this section.

Our Disaster Management System has a System Interface that communicates with various user interfaces and communication gateways. These interfaces are used together and able to propagate data, information and decisions in order to carry out day to day transport management operations, policy implementations, and emergency response operations. The Intelligence Layer consists of various mathematical models, algorithms and simulations, both stochastic and deterministic. These models accept transport related data received from various sensors such as inductive loops, intra-vehicular sensor networks, VANETs communications, and user interfaces.

The data received from various sources goes through an internal validation layer before it is accepted by the modelling and analysis layer. The modelling or simulation algorithm is used for a particular activity based on the nature of the activity. Mainly, there are two major cases can be considered which represent the most activities.

Emergency response systems are an extreme example because, firstly, the availability of real-time data may be greatly limited due to the unavailability of many communication sources due to a disaster (e.g. broken communication links), and secondly, the time period in which the system has to act would be short. In such cases, macroscopic models which require relatively small computational time and resources may be the only option.

While, in some cases, it is necessary and/or affordable to employ microscopic traffic models, for example, in developing transport policies and procedures; this is due to the demand for higher accuracy and greater flexibility on the available time for decision, optimization and analysis. In other cases, microscopic simulations may not be necessary, or may not be possible, due to the real-time nature of operations such as day to day transport management operations. This model will be developed and employed in Chapter 7 and Chapter 8.

This research also looked at ways of enhancing our distributed algorithms so we could invoke the most precise models for real - time critical situation such as serious disasters. It is important to note here that a cloud infrastructure is used which is virtualized and flexible in order to exist and transferable to outside the area affected by the disaster. This is possible considering the capability of cloud technology.

We focus on disaster management system, and some details of a macroscopic model that is used has been presented here for emergency situations where time to act is short and real time information is limited due to possibly broken communication links.

To examine our Intelligent Disaster Management System, a macroscopic model was used to represent the traffic in the city [213]. The model can be used to analyse the behaviour of traffic in road sections, and describe the dynamic traffic characteristics such as speed (v), density (ρ), and flow (q). The model is derived by using the following equation:

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho v}{\partial x} = 0 \ldots \ldots \ldots \ldots (5.1)$$

Where ρ is the traffic density in vehicle/km, and v is the traffic velocity (speed) according to distance x and time t. By using the Greenshield traffic model, the relation between ρ and v could be as follows:

$$v(\rho) = v_{max} * \left(1 - \frac{\rho}{\rho_{max}}\right) \dots \dots \dots \dots (5.2)$$

Where v_{max} is the maximum speed, and ρ_{max} is the maximum density. The fundamental relationship between flow, density, and speed is given by:

$$q = \rho * v \dots \dots \dots \dots (5.3)$$

Here, the flow and volume have been used interchangeably. Having given here the mathematical description of the macroscopic model that is employed, in the next chapter, a description is given for our approach for city evacuation in a disaster emergency situation.

5.2   The system implementation

Time - dependent traffic investigation on a transportation network has not been widely studied in the transportation literature, especially in disaster problems [193]. However, it can be stated simply as, we define the affected area and find out the flow rate of each link. This can be done by using different simulation models and hence processing the data provided by various communication technologies and finally propagating effective evacuation strategies.

Figure 5.2 depicts the system implementation including our Intelligent Disaster Management System. A city may be exposed to various disaster scales where the transportation and the communication systems performance will be disrupted seriously. Subsequently, the transportation system; including different applications, infrastructures and communication systems that are in use, are required to be assessed, addressed and might be re-set to make sure it is capable to deal with different disaster scenarios. Here, we predict our Disaster Management System is to be in place to avoid and reduce damage. Hereby, we represent the process through demonstrating the disaster management including various scenarios via OmniTRANS software, it could be presented in three stages below:

Stage I, it is called Real World Data (pre-disaster stage/base situation). This model observes the city transportation system behaves in a normal situation (real life situation) where drivers can complete their trip without any obstacles. The city model can be read, in our case by macro-simulation software which runs a timestep simulation. The model manages a set of vehicles as they start a trip, follow the rules of the road, interact with each other and finally arrive at their destination. The software reports on them as they travel. Also, it has been assumed that an evacuation plan is prepared in advance and ready to be used depending on the severity.

At same stage, unpredicted event hits the city. The stochastic situation can be visualized in this stage and the critical scenario was spotted through testing different disaster scales on different city characteristics at different locations to obtain the worst scenario. At this stage, the available city model will be tested and analysed, it is a database of the whole traffic network including the flow, speed, delay, links and junctions; signals and also a database of the travel demand in the city (the O-D matrix).

Stage Π, the Disaster Management System Operation, is the first step towards intelligent stage in the operation. It consists of important cooperation between wide ranges of different components within the proposed disaster management system. The cloud infrastructure layer provides the base platform and environment for the intelligent disaster management system. Also, we have the VANET communication layer interface which acquires data from various gateways.

Stage III, the Evacuation Strategies Operations. The effective decisions will be dispatched to vehicle's driver in real – time. It includes the static and dynamic traffic model system. Static Evacuation Strategies Operation, III, A includes a time based Origin Destination (O-D) matrix that shall be observed and controlled in order to provide and propagate the effective decisions and strategies to the vehicles and other nodes in real time. Decisions can be dispatched to encapsulate the demand trips to get to the safe areas. Moreover, stage Π can be detected and monitored dynamically and we can present huge benefits from applying the disaster management system in time intervals after assessing the situations. Therefore, hereby we created stage III, B.
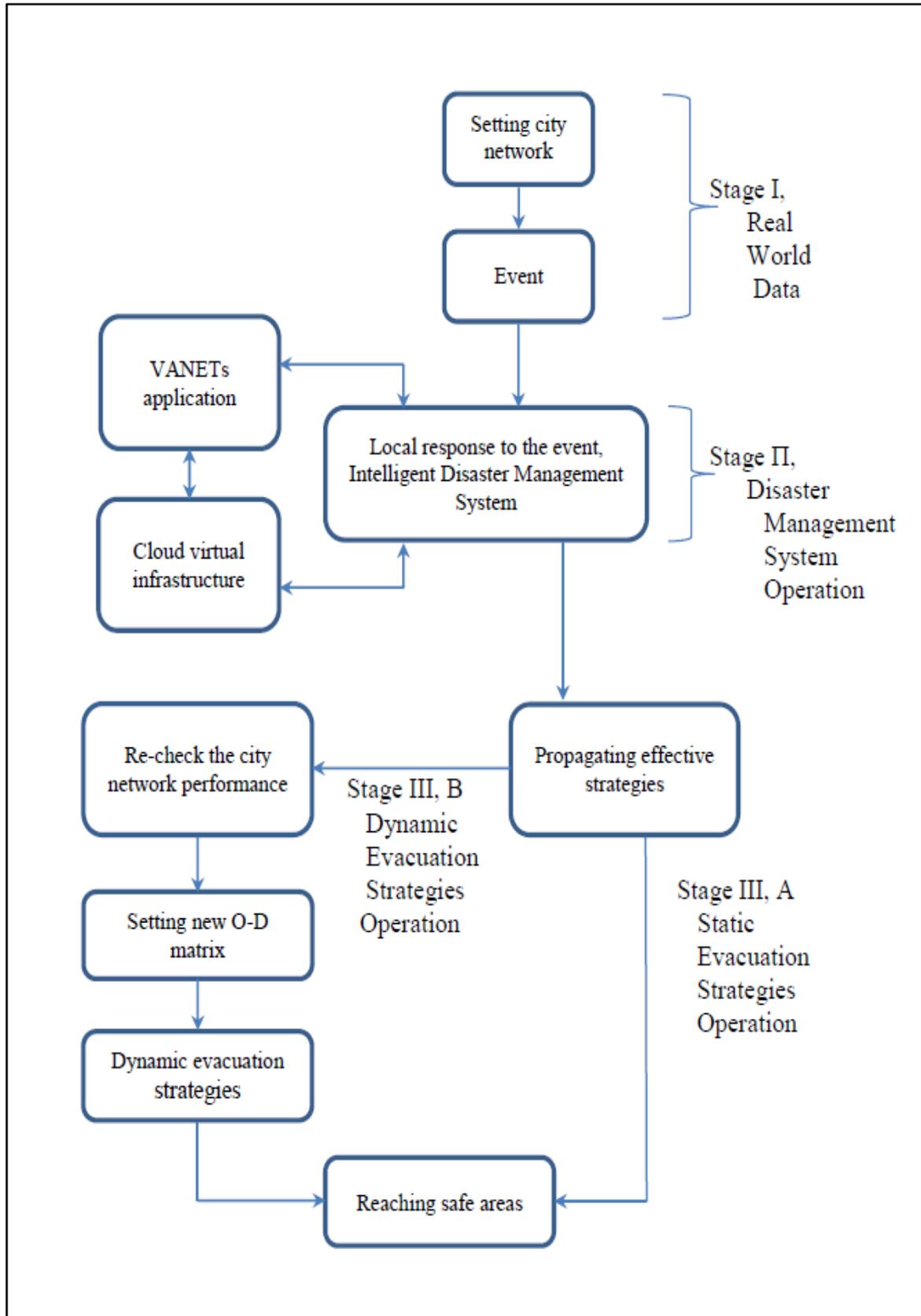
Figure 5.2 An Intelligent Disaster Management System operation

5.3   Message propagation via hybrid communications

The system proposed in Section 5.1 has been extended in this section. The system model is improved by means of introducing a novel message propagation algorithm through VANETs, and the effectiveness of the system was validated by means of extended simulation results. The earlier work was based on macroscopic traffic modelling. In our system, the Intelligent Layer also addresses how to forward messages in the vehicular environment in an optimal way, by means of opportunistically connecting vehicles whenever links are available. For this aim, a hybrid vehicular communications paradigm are considered which proves to be very suitable for achieving seamless connectivity in VANETs, wherein changes in the dynamic topology, vehicles' speed, as well as traffic density affect vehicle communications.

Connectivity management represents a challenge for VANETs, and more in general in disaster scenarios, where the network infrastructure is assumed to be not available in specific areas, additionally vehicle density and speed can quickly change. Exploiting both V2V and V2I represents an effective integrated solution for avoiding disconnections and guaranteeing seamless data communication [214] and [215]. In [214] the proposed approach, i.e. Vehicle-to-X (V2X), provides efficient message delivery in a vehicular grid, where vehicles opportunistically select the most viable communication protocol among V2V and V2I, and can switch from V2V to V2I, and vice versa. Here, we adopt the broadcast V2X approach from [214] into the ICDMS (Intelligent Cloud Disaster Management System) structure for emergency scenarios. The cooperation and coexistence of V2V and V2I can assure a good connectivity in such scenarios, especially in sparsely connected neighbourhoods where V2V communications are not always feasible. V2X can reduce the time required by a message to propagate from a source vehicle to the farthest vehicle inside a certain strip-shaped area-of-interest. Moreover, it represents a smart and realistic communication protocol, reduces the message delivery time, as well as avoids disconnections due to changed traffic density and dynamic topological changes. V2X is a pragmatic broadcast protocol where vehicles' actual transmission data rates are subjected to continuous changes due to physical obstacles, network density, speed, network overload, etc. Vehicles communicating via V2X get experience of local information, assumed as global. Each vehicle continuously monitors its local connectivity by storing HELLO broadcast messages. A vehicle will be aware of neighbouring

wireless networks on the basis of broadcast signalling messages sent by the Road Side Units (RSUs), as being able to determine if it is within a cluster or is travelling alone on the road.

Let us assume, for each connectivity link from the i-th to the j-th vehicle, the link utilization time τ (i, j) [sec.] as the time needed to transmit a message of length L [bit] from the i-th to the j-th vehicle, at an actual data rate f (i; j) [Mbit/s], such as:

$$\tau_{(i,j)} = {L}/{f_{(i,j)}} \ldots\ldots\ldots\ldots (5.4)$$

Please note that such definition applies also for connectivity links from a vehicle to a Road Side Unit. Let us define a path from i-th source vehicle to k-th destination node (i.e. vehicle or RSU), comprising a sequence of M hops. Each hop can be a link between two neighbouring vehicles via V2V or from a vehicle to a RSU via V2I. From the definition of a path, we define the path utilization time $T_{(i,k)}$ [s] from the i-th source vehicle to the k-th destination node as the sum of single link utilization time parameters for each hop that constitutes the path as:

$$T_{(i,k)} = \tau_{(i,j)} + \tau_{(j,x)} + \cdots + \tau_{(x,k)} = L \sum \left[f_{(i,k)}^{-1} \right] \ldots\ldots\ldots\ldots (5.5)$$

Among all the paths from a source vehicle to a selected destination node, the optimal path will be the one with the minimized path utilization time, such as:

$$\min T_{(i,k)} = L \cdot \min \sum \left[f_{(i,k)}^{-1} \right] \ldots\ldots\ldots\ldots (5.6)$$

Based on the estimation of the path utilization time (i.e., the message delivery time for a path from a source vehicle to a destination node), V2X is used to reduce the amount of hops needed to deliver the message. In disaster scenarios, where time is limited and connectivity links are possibly broken, a fast communication protocol which exploits time limited hops represents a viable approach. The message time novelty will be assessed in the next chapter.

ANALYSIS AND EVALUATION OF THE PROPOSED DISASTER MANAGEMENT SYSTEM

In the previous chapter, our intelligent disaster management system and the message propagation time algorithm are proposed and described in detail. This chapter is devoted to producing the results of applying our proposed system for each city in such emergency situations. This chapter presents the details of the modelling and analysis of our proposed disaster management system.

To this end, we use the macro-simulation model as a simulation platform to evaluate the proposed disaster management system impact on different urban environments. To run the software; OmniTRANS, it requires some information about network geometric design; such as major or minor roads, and essential road characteristics; such as capacity, traffic demand, flow etc. So, we need to collect these characteristics and rules, however, in our case we managed to get a real city data; we highlighted the important information of each city selected in Chapter 4; as described between Section 4.9.2 and Section 4.9.4.

Basically, the integration simulation model has been applied in three statuses, they are:

1. Existing or base case scenario,

2. Incident with no Incident Management (IM) scenario,

3. Incident with IM scenario.

It means for each city below, we will demonstrate the data in four statuses as the third scenario; Incident with IM scenario, consists of applying two different disaster management systems.

Precisely, two different real urban cities will be involved in this evaluation, Al-Ramadi city and Al-Huseneya city. The same steps assessment for Al-Ramadi city and Al-Huseneya city are assumed when comparing the performance of applying the three scenarios, and each scenario is described in details through different sections in this chapter.

A question might be raised; if we consider the same scenarios for each city, so what is the aim from various implementations? The reality is that major principal differences and similarities between the two cities are pinpointed starting from running the first scenario; normal situation, which affect input data process and eventually the system behaviour, toward other scenarios, a summary of the main features is revealed in Table 6.1. Furthermore, other differences can be recognized such as speed limit, flow, link capacity etc.

Table 6.1 Comparison between the two cities

Differences	Al-Ramadi city	Al-Huseneya city
Population of the city (capita)	230,500	125,000
No. of zones	5	2
Maximum no. of trips (veh/hr)	23787	10445
No. of evacuation area	2	1
Transportation environment	Urban environment	Urban environment

In this evaluation, an Integrated Multi-Modal Transportation Planning Commercial Package called OmniTRANS is used in the computation. OmniTRANS offers a modern integrated development platform for transport modelling. It is specifically designed to support multiple scenarios, modes and modelling techniques. It is a truly multi-modal multi-temporal system particularly suited to model the interactions of transport modes [216]. Further information is provided in Chapter 4.

First, different disaster scenarios are applied and then selecting the worst one. Then, we will apply our proposed disaster management system and compare the computational results to the obtained results of the scenario where our proposed system is not in place. Also, our evaluation measurements have been improved by employing different disaster management system dynamically in order to present the effectiveness operation. All these scenarios will be examined on Al-Ramadi city in between Section 6.1 and Section 6.1.5. Sections in between 6.2 and 6.2.3 present the analysis of the system on another city, to be able to establish and present the usefulness of our intelligent disaster management system. Section 6.4 shows simple manual calculation to present the AVO impact on the entire process. Finally, Section 6.5 shows some calculation to present the effectiveness of the developed algorithm.

6.1   The Al-Ramadi city and its transportation network

Al-Ramadi city lies in the west of Iraq; it is the centre of Al-Anbar governorate, is situated at the intersection of the Euphrates River and Al Warrar Channel, and on the northwest of Habbaniyah Lake. The city is 110 km west of Baghdad, 46 km west of Al Fallujah, and 283 km east of Rutbah. It lies on the major paths to Syrian and Jordanian boarders, so it occupies strategic planning concerns. The Euphrates River passes at the upper limit of the city, whereas, Al-Warrar Channel divides the city into two parts, see Figure 6.1.

The General Directorate of Physical Planning of the Ministry of Municipalities and Public Works (MMPW) is preparing for the Development Strategy of Al-Ramadi. The Association of the Canada-based HYDROsult Centre for Engineering Planning (HCEP) and the Iraq - based Engineering Consultancy Bureau of Al-Mustansiriya University has been commissioned by MMPW to carry out the tasks of this assignment and they have produced a two stage report for the development of the Al-Ramadi city [208] and [209]. Iraq is now open to new developments and it is a great opportunity to develop Intelligent Transportation Systems for Al-Ramadi and other Iraqi cities.

The topography of Al-Ramadi is generally characterized by relatively gentle slopes. Evidence of earlier settlement can be traced in the old section of the city where the town developed around the mosque and the market [208].

Figure 6.1 shows the transportation network map of the Al-Ramadi city, the network consists of zones, nodes, and links. The city is divided into 5 traffic zones; these zones are representing the sectors of the city and each sector is as homogeneous as possible and divided by natural barriers or major transportation streets, see Table 6.2. Zone 1 and Zone 5 are in the west side of Al-Warrar Channel which divides the city into two parts. Zone 1 represents the location of a huge glass factory; Zone 5 represents the west part of the city. The east part of the city contains Zones 2, 3, and 4. Zone 2 represents the old city centre which attracts a high number of trips in the morning peak hour. Traditional transportation analysis focuses on the classical peak travel demands of weekday morning journey-to-work and afternoon journey-from-work trips.

A focus on those times when traffic is at the peak makes sense when attempting to provide acceptable levels of service throughout the day, these zones are detailed in Table 6.2.

Table 6.2 An O-D matrix of the transportation network in Al-Ramadi city

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Total
Zone 1	0	0	0	0	0	0
Zone 2	82	0	172	935	228	1417
Zone 3	172	2757	0	1171	108	4208
Zone 4	343	10026	381	0	248	10998
Zone 5	272	4835	358	1699	0	7164
Total	869	17618	911	3805	584	23787
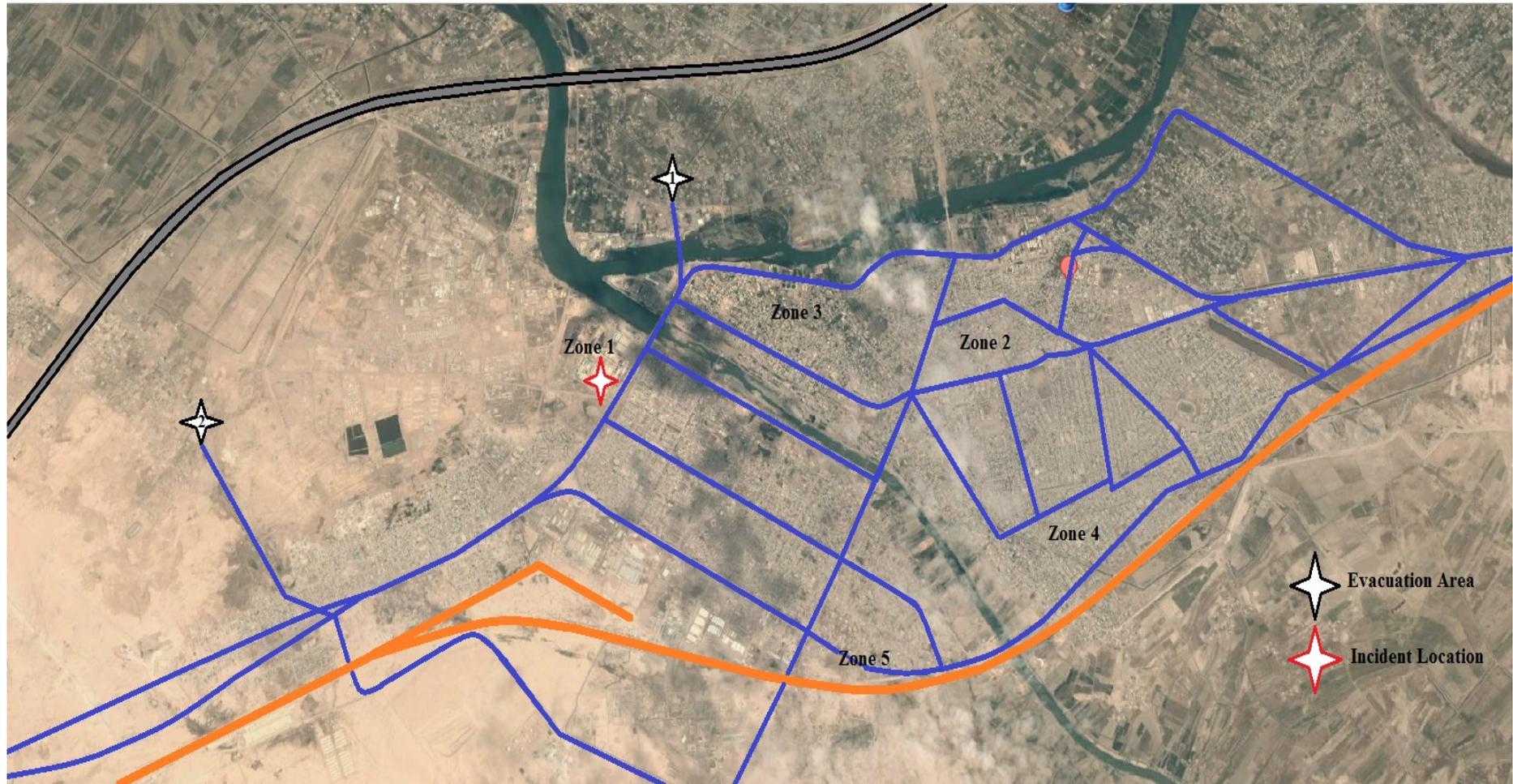
Figure 6.1 The transportation network of the Al-Ramadi city

The criteria of the urban traffic network depend on the real performance over time. Considerable data are available for Al-Ramadi city; the essential information which was observed, monitored and assumed for the operations, required to be applied in OmniTRANS software and the information are summarized in Table 6.3. The required data is collected using different methods such as manual recording, video camera recording and some relevant resources.

Table 6.3 Al-Ramadi city basic data

Measurement	Value
Population of the city (people)	230,500
No. of zones	5
Peak period	8:30 – 9:30 am
Maximum trips (veh/hr)	23787
No. of evacuation area	2

Note also in Figure 6.1 the two evacuation areas, Evacuation Area 1 and Evacuation Area 2. Their purpose is to provide an appropriate and safe location for the population in case a major disaster strikes the city and people need to be moved out of the city. The two evacuation zones are chosen in the north of the city, because there is an international roadway; it will be best provided through the international roadway, that joins the Iraqi borders with Syria and Jordan in the west with the capital Baghdad, and the evacuation zones are just a few minutes away from that road. The area in the east side of the city is mostly for agriculture land use and is private property.

The west street leads to a nearby city about 30 km away, this city has a good hospital but it can be best reached through the northern international roadway. In the south of the city there is the desert only and the connections of roadways in this area are very poor. If there is a need to give medical supplies or transport to injured and affected population.

A final note on the evacuation process, the public transportation vehicles in Al-Ramadi city consists of buses only. The public transportation vehicles will be involved, where possible, in the cases of emergencies, although it will need a decision from the City Council authorities.

6.1.1   The system evaluation

The basic mathematical models of the used macroscopic model are described in Chapter 5, and the hybrid communication protocol V2X and other major technologies have been illustrated in Chapter 3. In this section, we will describe some traffic information required and what can be assumed to be used as input files, and then assess the system according to the results which are obtained from different scenarios; disaster strikes the city and when applying the both disaster management systems; a traditional disaster management system and our intelligent disaster management system.

6.1.2   The disaster scenario

Consider Figure 6.1 which divides the Al-Ramadi city into 5 zones. In Table 6.2, we quantify transportation trends of the city in terms of an Origin-Destination (O-D) matrix between the five city zones. The numbers of trips in the O-D matrix shown are in the mid-week period with normal conditions. These trips are calculated using the Fratar model (which did not differentiate trips by purpose) [217]. Note that the highest rate of trips is toward destination Zone 2 in the city centre.

In Zone 1 lies a glass factory and beside it is Al-Warrar dam; both of these pose major risks to the city. This report considers the risks related to the glass factory and Al-Warrar dam as a case study in order to describe and evaluate our emergency response system. The related potential risks for disaster events in Zone 1 are outlined below:

- Fire hazards at the main factory.

- Technology failure due to shutdown of power plants that feed the city.

- Explosion of hazardous materials in the glass factory.

- Terrorist attack in the area of the factory.

- The collapse of Al-Warrar dam adjacent to the factory.

The above listed disaster events, except the last one, may last several hours before it can be controlled; for transportation planning purposes, special care is required to handle the emergency situation and save peoples' lives.

Now, the focus is on a disaster event which could happen in the glass factory. This event could be any one of the potential risks listed earlier in this section, e.g. fire or explosion of hazardous materials in the glass factory. The details of the event are as follows.

6.1.3 Timing of the disaster

The traffic conditions in a city typically vary during the course of the week. We consider that the event happens during the mid-week period, say on Tuesday.

Our methodology is independent of a particular day/time, although the traffic situation would vary depending on the day and time of the disaster event. Usually the most critical conditions in the traffic network are in the morning peak (herein between 8:30 am to 9:30 am) and evening peak hour (2:00 pm to 3:00 pm). These peaks are for official commuters but the commercial activity in the city centre usually begins after 9:00 am.

It has been considered that the incident happens at 9:00 am. The event causes the network to be closed in the Zone 1 and some nearby road links. A disaster management system is required, at this stage, to coordinate the city transport, communicate with the city population, and lead people out of the city to a safe location.

The traffic situation painted in the city network of Figure 6.2 and described in the section above is calculated using the macroscopic model; it represents a snapshot taken at 09:30 am, i.e. half an hour after the disaster incident has taken place. Thirty minutes after the event, when all the drivers in the event area might receive the information about the event. In other words, the 30 minutes period after the incident gives some opportunity to people to start heading towards, and reaching, safe places if provided (such as evacuation areas) outside the boundaries of the city, In this case of the Al-Ramadi city, people will be moved to the two evacuation areas.

This period also gives time for transmission of the information so most of the road users know what is happening and where they should be heading. The disaster response systems are discussed and evaluated next.

6.1.4   Static disaster management system assessment

Two scenarios for the disaster response system are considered and compared:

- Firstly, the traditional disaster response system where people will gain awareness of the disaster situation and response procedure through media such radio, television, telephones (given that such means are still accessible), and through their physical environment (e.g. interacting with the people who are in the nearby area).

- Secondly, our Cloud-based intelligent disaster response system are employed, which automatically collects data; intelligently processes the data; and, devises and propagates effective strategies and decisions based on the real-time situation, in line with appropriate policies and procedures already in place in the system. Consequently, the evaluations of the two systems are completed and compare their performance.

6.1.4.1   A traditional disaster response scenario

A disaster usually causes most people who are in its vicinity to move away from the disaster location. The panic sets off and people start pushing each other without any effective coordination.

The situation with vehicles becomes no different, as in the absence of any effective coordination, the roadway sections around a disaster area are blocked, and the incident will spill over like a shockwave over the entire network system. Such a reaction for the Al-Ramadi city caused by a major disaster in the glass factory is depicted in Figure 6.2. The figure represents the situation where there is no information transmitted due to the disaster which means there are still trips entering the city and there is no orientation of trips to get people to the safe areas. Meanwhile, due to the blockage of roads, the path to the Evacuation Area 1 is blocked and then every effort to reach Evacuation Area 1 is useless and makes the situation in the network more complicated.

Note also in the Figure 6.2 that the roads, near the factory, that connect Zone 1 with Zones 3 and 5, and with Evacuation Area 1, all are blocked (depicted by the roads coloured in black). Also note that the roads connecting Zones 2, 3 and 4 with each other, all have very low volume below 500 vehicles per hour (depicted by the roads coloured in red). A further notice that a couple of roads near Zone 2, nearer the outer boundaries of the city, with volumes between 500 and 1000 vehicles per hour (represented by roads coloured in blue).

Furthermore, it has been noticed that the roads which are located at the outer boundaries of the Ramadi city are coloured in brown and green, depicting higher volumes, between 1000 and 1500 (brown), and greater than 1500 vehicles per hour (green), respectively.

The vehicle volumes that have been computed using our models amounts to 660 vehicles per hour (400 vehicles in the first 30 minutes) after the glass factory incident for Evacuation Area 1, and 2200 vehicle per hour (1000 vehicle in the first 30 minutes) for Evacuation Area 2. Clearly, there are many more vehicles (almost 4 times) reaching Evacuation Area 2 compared to Evacuation Area 1.
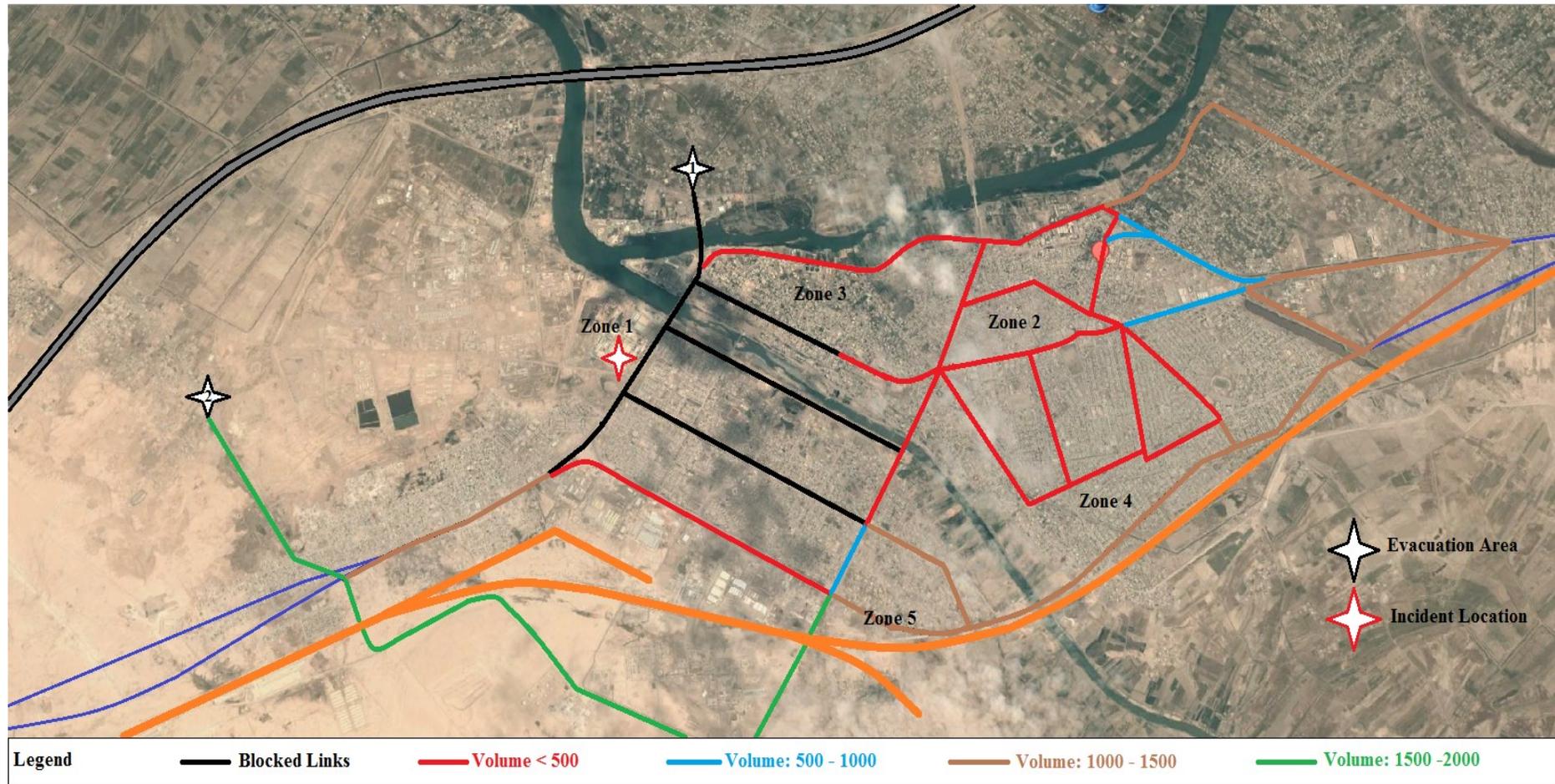
Figure 6.2 The transportation network of Al-Ramadi city with traditional disaster response system

6.1.4.2   Intelligent disaster management system

Now, the evaluation is will be made for our proposed VANETs and Cloud based disaster
management system. All the disaster scenario conditions are the same as in the previous
section including the role of public transportation in the evacuation process. The difference
lies in the ability of the system to:

- Acquire real-time data, and establish communication through VANETs, smartphones
  and social networks,

- Process the data and devise an optimum strategy by data analysis, and

- Coordinate and control road traffic and other efforts through dissemination of
  information and management of the available transport infrastructure (e.g.
  controlling traffic signals if possible, sending a route map to the traffic navigators
  and other GPS enabled devices etc.).

These three steps are iterative and can provide a periodic update to take any real-time changes
into account. For instance, the macroscopic modelling in the Intelligence Layer could be used
to periodically compute an O-D matrix depending on the type of disaster and real-time traffic
conditions. The O-D matrix then can form the basis of information that is propagated to the
transport infrastructure and authorities individuals and groups. Furthermore, certain boundary
conditions will be enforced on the city through traffic management systems and authorities,
such as (i) there will be no entry in the city, (ii) no entry in the area of event, (iii) many routes
will be changed into one way flow outside the event area etc.

The road traffic network situation after the disaster hits the Al-Ramadi city is depicted in
Figure 6.3, this time though we have exploited our proposed disaster management system to
curtail the disaster impact. As in Figure 6.3 the network represents a snapshot taken at 09:30
am, half an hour after the disaster incident has taken place.
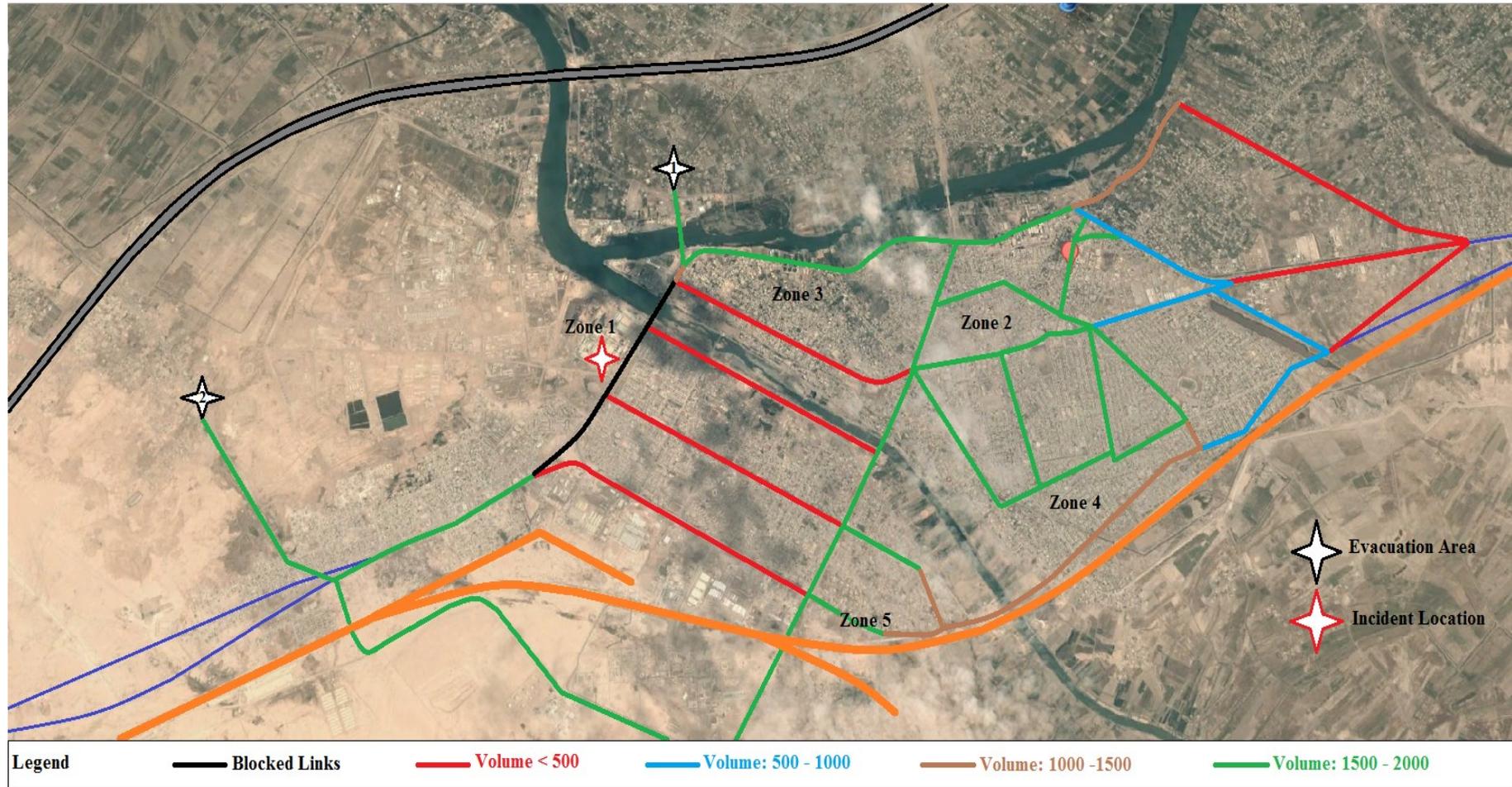
Figure 6.3 The transportation network of Al-Ramadi city with our disaster management system

Take a quick look at the two figures, Figure 6.2 and Figure 6.3, and note the differences – do you see in Figure 6.3 less black and red and more roads in green. Note also that the roads leading to both evacuation areas are now green representing clear roads and high flow (1500 - 2000 vehicles per hour).

Moreover, in Figure 6.3, note that a greater part of the city centre has roads with free flow (i.e. in green colour) except the roads between Zone 1 and Zone 5 which are coloured in red, representing low flow at less than 500 vehicles per hour. The road next to the glass factory is coloured black and represents a broken link. Also, a few roads near Zone 2, nearer the outer boundaries of the city, with low (red), medium (blue) and medium high (brown) volumes. These low volumes, it is believed that because of the use of alternative roads available in this case towards Evacuation Area 1.

Based on the computations and our models, 2660 vehicles per hour (1260 vehicles in the first 30 minutes) are being evacuated to Evacuation Area 1, and 2860 vehicle per hour (1530 vehicle in the first 30 minutes) are evacuated to Evacuation Area 2.

The evacuation volume per hour is almost similar for both evacuation areas. This is clearly a balanced use of the two evacuation areas, an improvement over the traditional disaster management approach reported earlier where the use of Evacuation Area 1 was significantly smaller.   Table 6.4 shows the considerable advantage of using the intelligent disaster management system in reducing the evacuation time for the Al-Ramadi.

Table 6.4 Results of two methods for Al-Ramadi city

	Traditional systems	**Using VANETs system**
Total Time of Evacuation (minutes), approximately	330	160
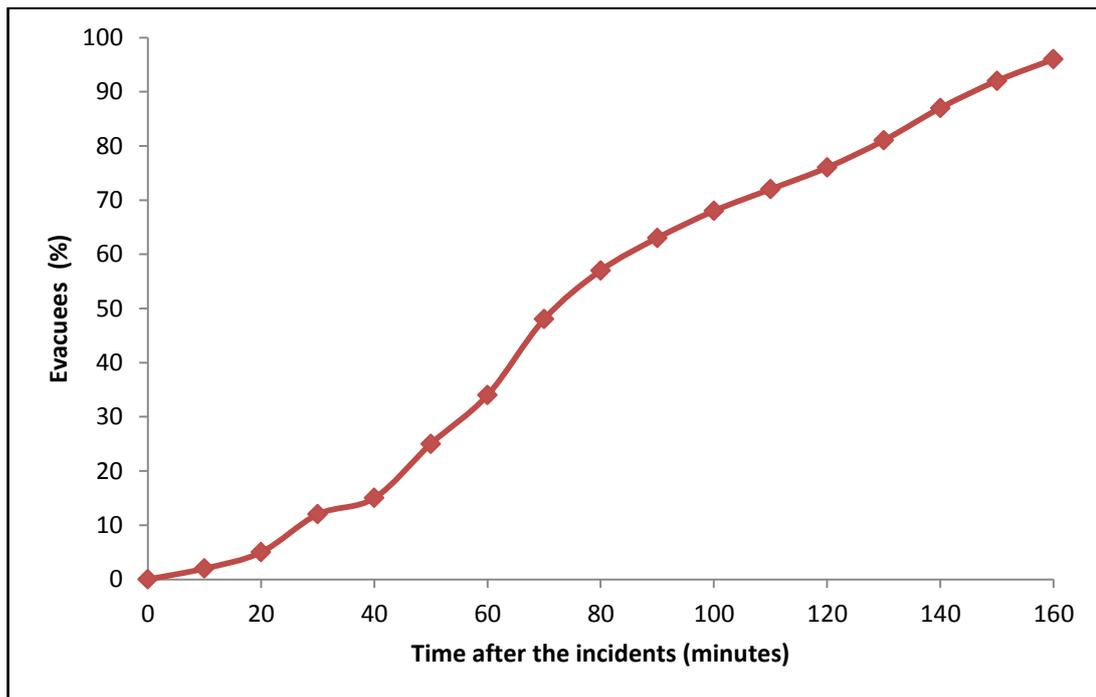
Figure 6.4 The percentage of people evacuated from the city against time in the Al-Ramadi
city using intelligent disaster management system

Figure 6.4 depicts the time dependent process of evacuation of the residents of the Al-Ramadi city. The figure shows that 30 minutes after the incident only 12% of the people have been evacuated. This is mainly due to social habits and characteristics of the population (an extensive study of the demographics, regional, topographic, environmental and economical characteristics of the Al-Ramadi city, along with its infrastructure and major development issues can be found in [209]). About 50% of people that are in the risk area are indoors. The evacuation of the people indoors mainly begins after 30 minutes from the time the disaster struck the city.

6.1.5   Dynamic VANET based traffic sensing and control

The previous implementation sections presented a stepwise approach to the intelligent VANET Cloud based traffic control for evacuation management during major disasters. The approach is stepwise, static, because the cloud based intelligence layer computes the disaster strategy only once and propagates the devised control plan to the vehicles so that the vehicles

could find their routes to the evacuation areas based on their locations. In this section, we enhance our earlier approach by extending the earlier static methodology to a dynamic one.

In addition, the possibility to introduce a dynamic system is promoted; the traffic performance will be examined and evaluated dynamically, per a fixed time period; say every 10 -15 minutes, the traffic situation will be checked and hence the decisions updated according to the new situation (consistently be able to collect the data and propagate the decisions). In other words, the dynamic approach exploits the fact that the road and disaster conditions can be sensed periodically, in real time, through vehicular networks and other sources, such as road traditional sensors (inductive loops, traffic counters etc.), cameras, social networks, traffic authorities etc. (if these are still functional after the disaster).

Before starting the assessment, very important factor should be clarified; the time interval. There is no observed either assumed evidence have been utilised leading to the choice of the time interval for announcing people to evacuate from diverse zones. In disaster problem, it has been noted that some challenges are faced during selecting a time-step at the same period for both short and long links. To model the short links in a very short time step is essential, although this will accelerate the problem size. However, the sensitivity of travel time is the core concern to the selected time-step. To elaborate the time sensitivity, for example if 1 minute is applied to a short interval time it may be worthy for the short links opposite to the effect shown by the long links. On the other hand, to predict the travel time between two nodes that are a thousand miles apart, with accuracy of 1 minute is almost impossible. In this state, to achieve the effectiveness time interval sensitivity, 1 hour to 30 minute unit is more applicable [218]. For example, 1 minute intervals is applicable for simulating very small size road networks, however it is not ideal. The reason being is, the study area is very small and they conducted short period time to clear the road network.

To sum up, to achieve the set goal; which is setting a suitable time-step to evacuate people in such problem, the evacuation scenarios can be duplicated many times through applying different time-steps, so establishing a suitable interval time can be started.

Here, the traffic condition periodically can be assessed every 10 -15 minutes, giving sufficient time to sensing the traffic, compute a suitable traffic assignment strategy, and propagate the computed strategy through vehicular networks, traffic control signals (if these are functional) and other dissemination and control sources.

All the other settings, except dynamic sensing and control, described in the previous section remain the same. This approach allows any transient effects in the city traffic to be taken into account in real-time (every 10 - 15 minutes in this case but the time can be decreased or increased to suit the disaster situation) and have a real-time automated control over the evacuation plan. An example of the results for the dynamic modelling approach is presented including figures between Figure 6.5 and Figure 6.6.

Figure 6.5 shows the cumulative number of vehicles against time on the Al-Am Street in the east side of the city (see map and streets in Figure 6.1). In addition, Figure 6.6 shows the cumulative number of vehicles against time on the Ceramic Street in the west side of the city.
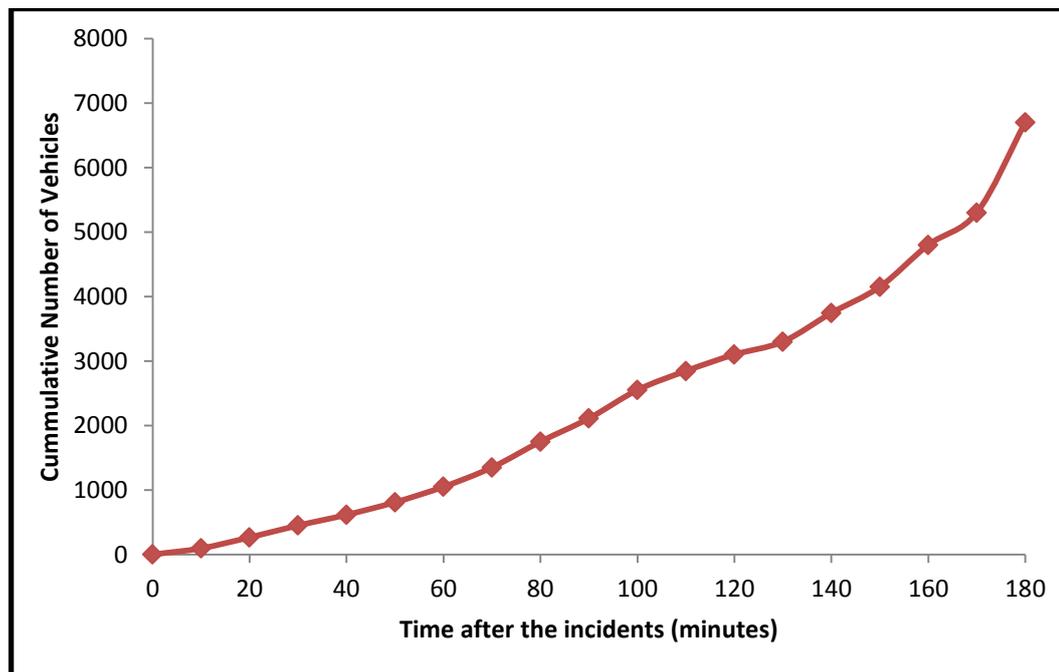
Figure 6.5 The cumulative number of vehicles against time in the east side of the city
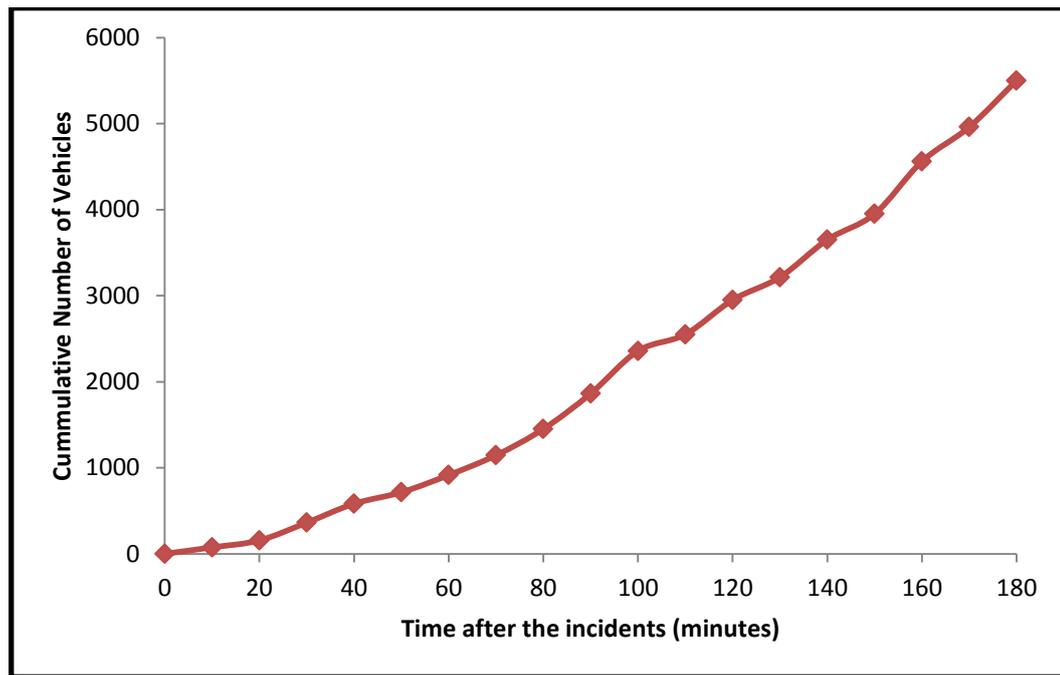
Figure 6.6 The cumulative number of vehicles against time in the west side of the city

6.2   Al-Huseneya city

Al-Huseneya city is a major district in the Karbala Governorate, and is situated 15 km to north east of Karbala city, and 70 km at the south of Baghdad city, the capital of Iraq. Most of the population of Al-Huseneya is rural, according to censuses at the year 2007. The overall population of Al-Huseneya is estimated around 125,000 capita [210], the city map can be seen in Figure 6.7.

Figure 6.7 shows the transportation network map of Al-Huseneya city, the network consists of zones, nodes, and links. The city is divided into 2 traffic zones. Zone 1 is on the west side of the major street which divides the city into two parts. The east part of the city contains Zone 2 represents the old city centre which attracts high number of trips in the morning peak hour. The surrounding areas around the city are major agriculture areas and the connections of roadways in these areas are very poor.

Also, we quantify transportation trends of the city in terms of an O-D matrix between the two city zones in Table 6.5. The numbers of trips in the O-D matrix shown are in the mid-week period with natural conditions. These trips are calculated using the Fratar model.

Table 6.5 An O-D matrix of the transportation network in Al-Huseneya city

	Zone 1	Zone 2	Total
Zone 1	0	3050	3050
Zone 2	7395	0	7395
Total	7395	3050	10445

Most effective emergency plans should consist of specifying the evacuation area location in advance so it becomes possible for people at risk to be directed to those safe areas. Note in Figure 6.7, the evacuation area, its purpose is to provide an appropriate and safe location for the population in case a major disaster strikes the city and people need to be moved out of the city, so the evacuation area was chosen in the south of the city, because there is a direct roadway that joins the evacuation zone with Karbala city, the capital of Karbala Governorate. The surrounding areas around the city are major agriculture areas and the connections of roadways in these areas are very poor. The data received from various sensors; such as video recording, intra-vehicular sensor networks and user interfaces, goes through an internal validation layer before it is accepted by the modelling and analysis layer.

A disaster event which could happen in the business district area is selected and could be any one of the potential risks listed earlier in Section 6.1.2, e.g. fire or explosion of hazardous materials in the market areas, disaster area is determined in Figure 6.7.
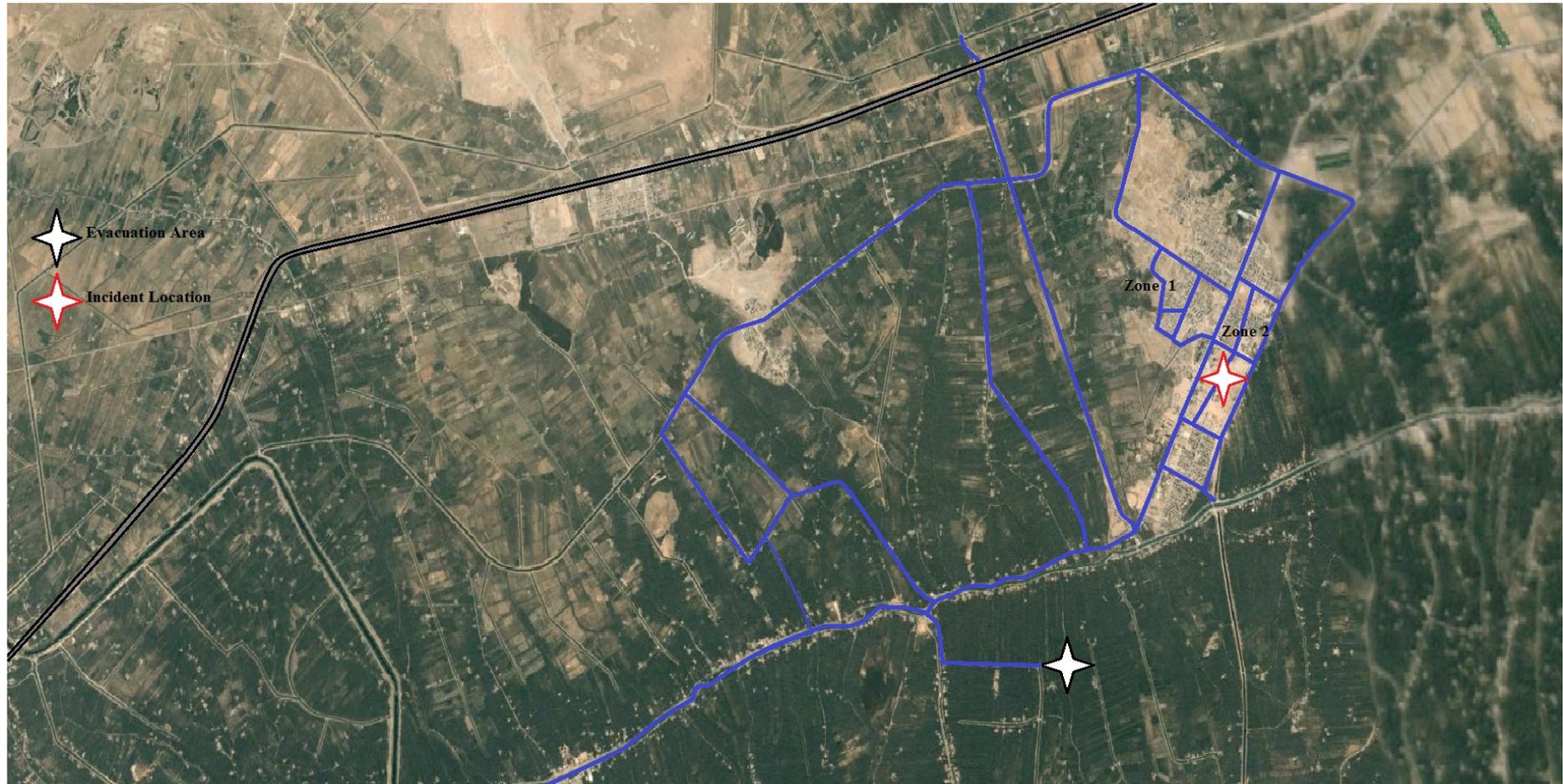
Figure 6.7 The transportation network of Al-Huseneya city

Now, the fundamental transportation information are listed, which are used in the disaster management operations for Al-Huseneya city; they are summarized in Table 6.6.

Table 6.6 Al-Huseneya city basic information

Measurement	Value
Population of the city (people)	125,000
No. of zones	2
Peak period	8:00 – 9:00 am
No. of trips (veh/hr)	10445
No. of evacuation area	1

Next, the comparison results between the implementation of our proposal, intelligent disaster management system, and the conventional system are presented.

6.2.1 Timing of the disaster

The traffic conditions in a city typically vary during the course of the week. This study considers that the event happens during the mid-week period, say on Wednesday.

As mentioned in previous city, the most critical condition in the traffic network is in the morning peak (herein between 8:00 am to 9:00 am) and evening peak hour (2:00 pm to 3:00 pm). We consider that the incident happens at 8:30 am. The event causes the network to be closed in the Zone 2 and some nearby road links, a disaster response system is required at this stage.

6.2.2   Disaster static scenario

6.2.2.1   A traditional disaster response scenario

Such a reaction for the Al-Huseneya city caused by a major disaster in the business district area is depicted in Figure 6.8. Note in the figure that the major road between Zone 1 and Zone 2 with the evacuation area is almost blocked and has very low volume below 500 vehicles per hour (depicted by the roads coloured in red). Further notice that the other roads near Zone 2, nearer the outer boundaries of the city, with volumes between 500 and 1000 vehicles per hour (represented by roads coloured in blue). Furthermore, we note that the roads which are located at the outer boundaries of the Al-Huseneya city are coloured in orange and green, depicting high to very high volumes, between 1000 and 1500 vehicle per hour, and more than 1500 vehicle per hour respectively.

In safe evacuation area, the vehicle volumes that have been computed using our models amount to 600 vehicles per hour for the first hour (350 vehicles in the first 30 minutes) after the incident.

The traffic situation painted in the city network of Figure 6.8 and described in the paragraph above is calculated using the macroscopic model; it represents a snapshot taken at 09:00 am, i.e. half an hour after the disaster incident has taken place.

A quick calculation has shown that, to evacuate the 125000 population of the city; 20% of people have access to private cars, and assuming the AVO is 5 passengers per vehicle, so it would take around 2.5 hours to evacuate them. Additionally, 80% of people will be evacuated by using the public transportation where the mean number of passengers is 17 people in the vehicle according to the classification of buses. So, to evacuate the 80% of people, it has been estimated that around 3 hours are needed to reach the safe areas. Consequently, ideal time we require to finish the evacuation process is 5.5 hours. The difference in people's percentages, 20 % and 80 %, is related to many factors such as:

- Most residents receive low income which could result in low ownership.
- Large families own one private car.
- Cultural restriction.
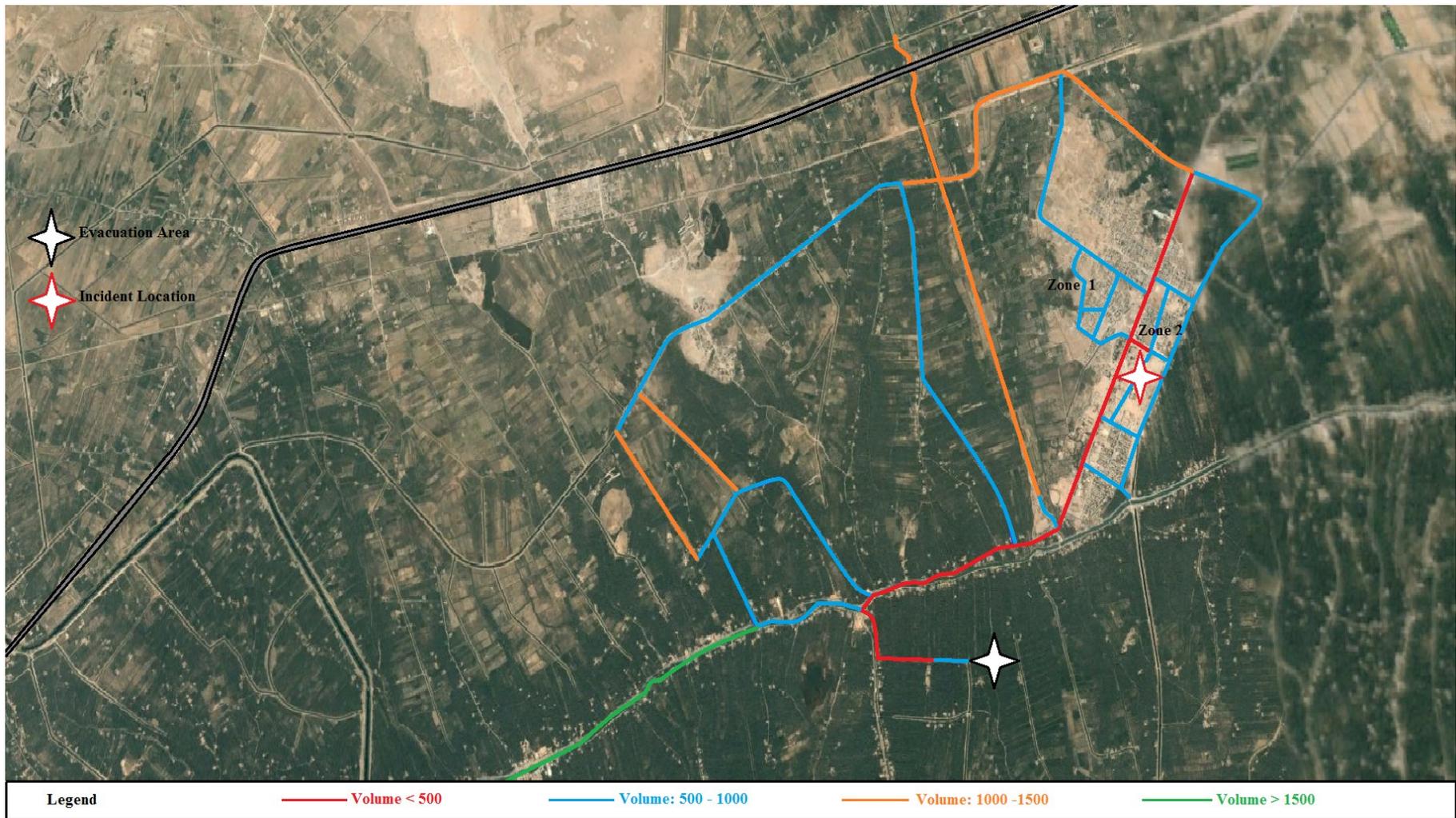
Figure 6.8 The transportation network of Al-Huseneya city with traditional disaster response system

6.2.2.2 Intelligent VANET Cloud disaster response scenario

The proposed VANETs and Cloud based disaster response system is evaluated. All the disaster scenario conditions are the same as in the previous section including the role of public transportation in the evacuation process. The same issues, mentioned in Section 6.1.4.2, for the Al-Ramadi scenario should be considered. These three crucial phases can provide a periodic update to take any real-time changes into account.

This time though, we have exploited our proposed disaster management system to curtail the disaster impact. As in Figure 6.9, the network represents a snapshot taken at 9:00am, half an hour after the disaster incident has taken place. Take a quick look at the two figures, Figure 6.8 and Figure 6.9, and note the differences – do you see in Figure 6.9 the absence of red and more roads in blue? Note also that the roads leading to the evacuation area are now green representing clear roads and high flow (1500-2000 vehicles per hour). Moreover, Note that a greater part of the city centre has roads with a stable flow (i.e. in orange colour) except the major street in the city; the roads next to the central business district coloured blue.

Based on the computation using our models, 1800 vehicles per hour (650 vehicles in the first 30 minutes) are being evacuated to the Evacuation Area. To evacuate the 125000 population of the city, 220 minutes were needed to finish the evacuation process.

Also the results of our model are compared with the results of the OmniTRANS Package. The evacuation volume per hour at the roads leading to the evacuation area are balanced, an improvement over the traditional disaster management approach reported earlier where the use of Evacuation Area was significantly smaller and took a much longer time.

Table 6.7 shows a comparison between using the traditional method and the VANET disaster management system in Al-Huseneya city.

Table 6.7 Results of two scenarios for Al-Huseneya city

	Traditional method	Using VANET
Total Time of Evacuation (minutes), approximately	310	220
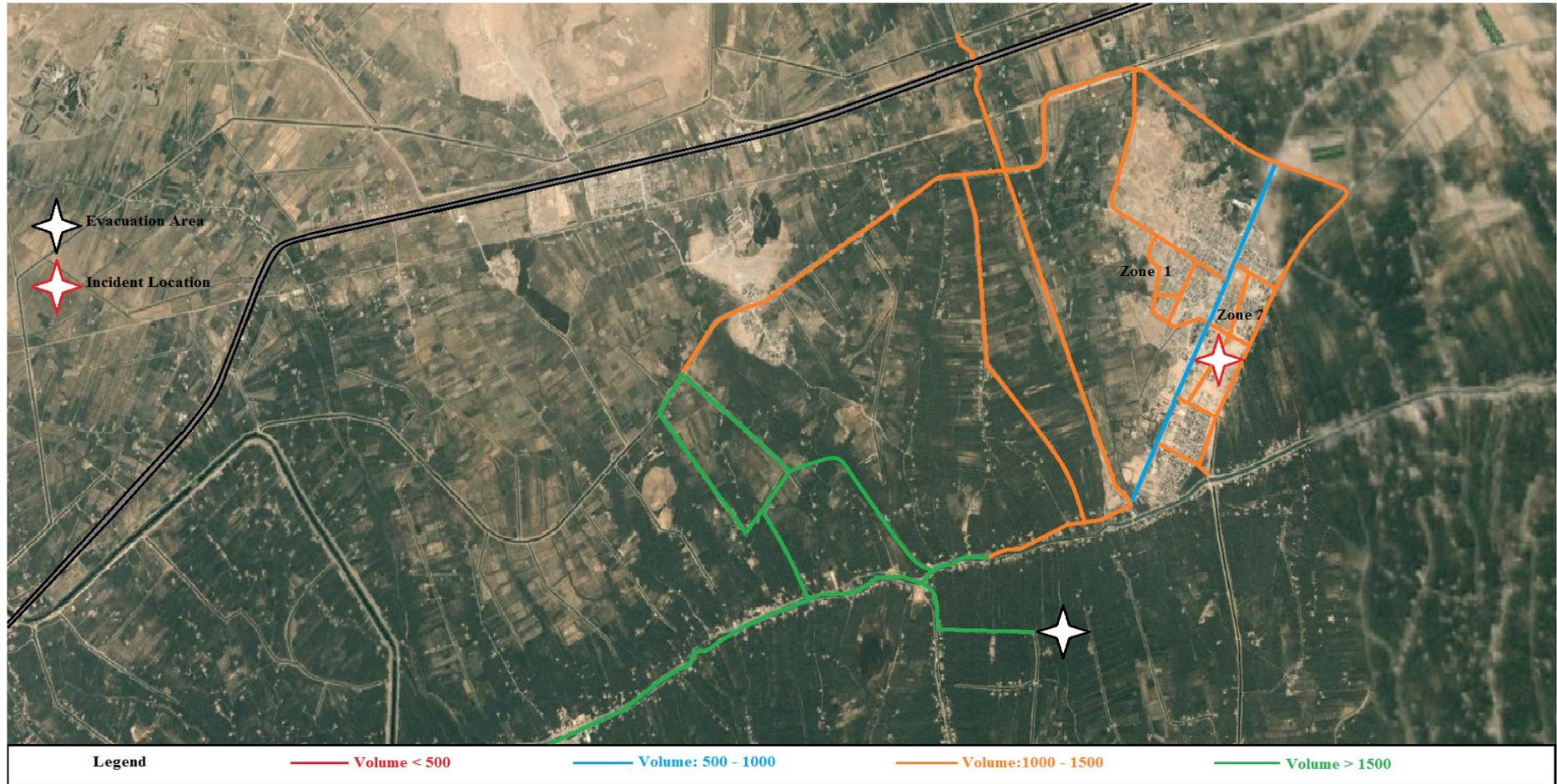
Figure 6.9 Transportation network of Al-Huseneya city with our disaster management system

6.2.3   Dynamic system assessment

In this section, and again we introduced a dynamic system; the traffic performance will be examined and evaluated dynamically, per a fixed time period; say every 10 -15 minutes, and the traffic situation checked and hence the decisions updated according to the new situation (consistently be able to collect the data and propagate the decisions).
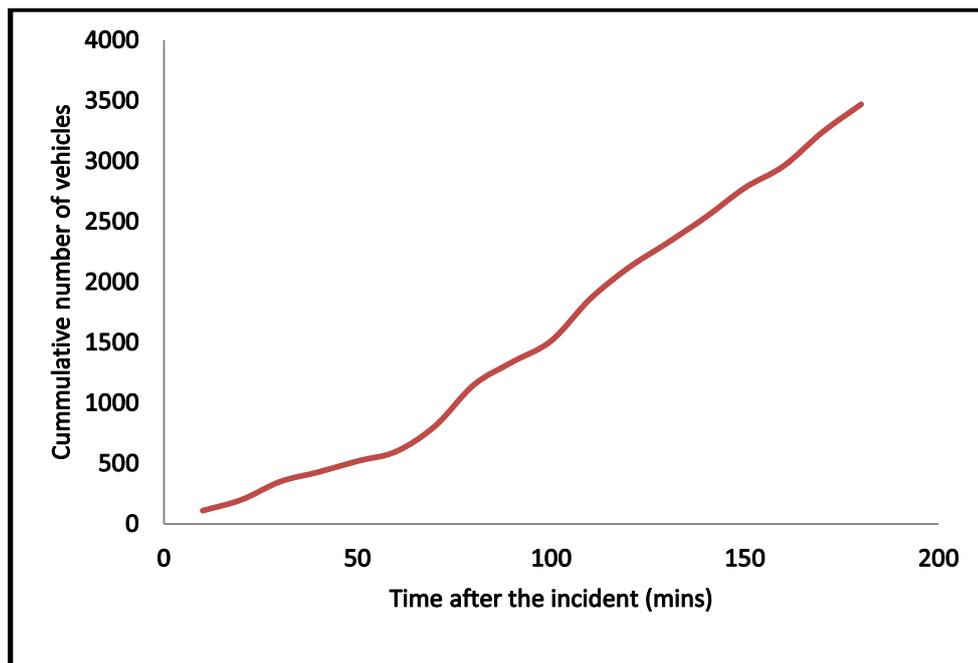
Figure 6.10 The cumulative number of vehicles against time in the Al-Huseneya city using traditional disaster response system

Figure 6.10 shows the cumulative number of evacuated vehicles against time in the Al-Huseneya city using the traditional disaster response system on the main Street that divides the city into the two zones (Zone 1 and Zone 2) (See map and streets in Figure 6.7) which is in red. That high volume shows that there is a problem in the street and this may lead to a serious congestion problem through the evacuation process.
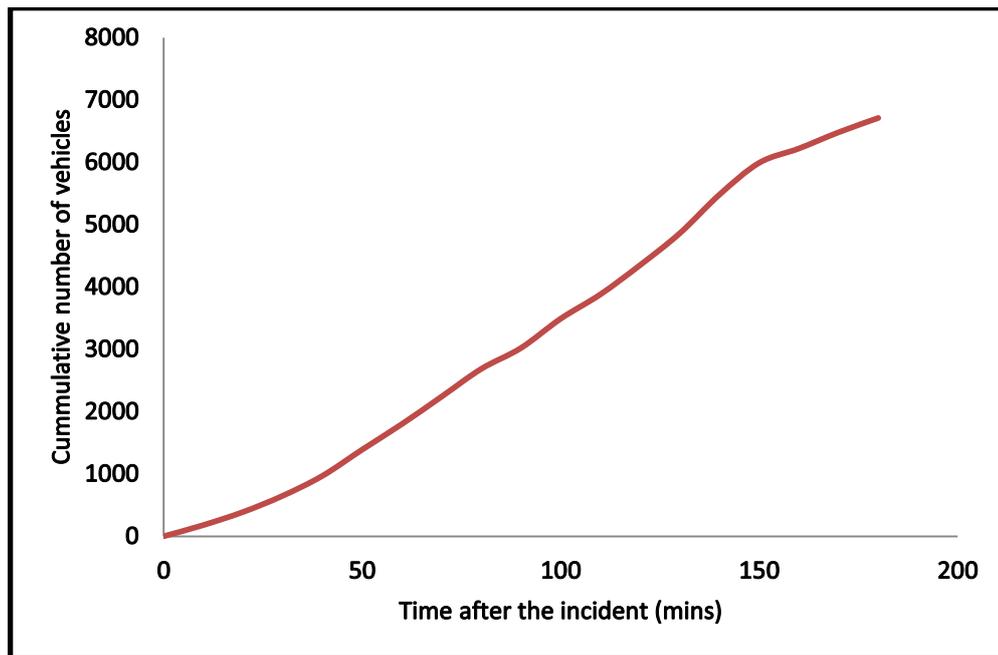
Figure 6.11 The cumulative number of vehicles against time of the Al-Huseneya city with our disaster management system

Figure 6.11 shows the cumulative number of evacuated vehicles against time of the Al-Huseneya city with our disaster management system. As mentioned earlier, the data are collected, the control strategy is computed and propagated at 10 - 15 minutes intervals. From Figure 6.11 it is demonstrated that the volume in the main streets is steady and controlled by using our disaster management system dynamically. This system has the capability to encapsulate any incidents that may happen because of high communication ability with the road users.

Note the two charts, Figure 6.10 and Figure 6.11, the attention brings obvious difference between the accumulative numbers of evacuated vehicles for each scenario, as the proposed system shows an improvement achieved in the total number of vehicles evacuated.

6.3   Comparison between Al-Ramadi and Al-Huseneya results

In this study, it is very important to select different cities features to test the system proposed, this is because the ability to demonstrate the intelligent disaster management system and represent the significant importance acquired while taking into account many city features, different contexts. Consequently, the ability to generalize the system usage is tested.

Some factors are defined and considered where they directly affect the implementation. When choosing the cities to test the project objective, several differences static characteristics are considered such as population, city dimension, people attitude, no. of zones and no. of trips, see Table 6.1. These differences eventually affect the no. of evacuation strategy selections and the evacuation time for both scenarios. Consequently, Table 6.8 shows the significant difference between two cities selected for this study (after implementing different disaster management system including our intelligent proposed system).

Table 6.8 Comparison between Al-Ramadi and Al-Huseneya main results

	Al-Ramadi city	Al-Huseneya city
Total time of evacuation using traditional system, static mode, minutes	330	310
Total time of evacuation using our proposed system, static mode, minutes	160	220
Total time of evacuation using traditional system, dynamic mode, minutes	135	180
Total time of evacuation using our proposed system, dynamic mode, minutes	115	120

Note Table 6.8, it is noticed that there are obvious differences between the two cities and for both static and dynamic implementation. This is because we employ different strategies and models, the traditional static model causes high delays due to many obstructions happened in

the traffic network, long response time of both the management agents and vehicle drivers. This delay decreases when the dynamic mode is applied which implies the O-D matrix required every time segment and all the blockages are entered the transportation network after few minutes from its appearance. Our proposed system gives the opportunity of fast response time where the drivers will aware immediately about any changes in the network. When the dynamic system which imply the dynamic changes in the O-D matrix, the total evacuation time will be decreased rapidly and consequently reduce the potential causality of losses.

6.4   Average Vehicle Occupancy (AVO)

To enhance the damage reduction, there is an opportunity to use the public transportation vehicles to enhance the evacuation process. For example, Al-Ramadi public transportation system consists of buses only. The public transportation vehicles will be involved, where possible, in the cases of emergency, although it will need a decision from the city council authorities.

Since public transportation vehicles have a high passenger capacity, these will be useful in the evacuation process. According to this level, we investigate and present here a very important factor which affects the disaster management system operation; it is called Average Vehicle Occupancy (AVO). Vehicle occupancy treatment takes a great part in the evacuation process; the higher rate of car occupancy means fewer trips required in the evacuation process, this may have the following benefits:

- Reducing any unnecessary movements of cars

- Increasing vehicle utilization.

- Increasing the transportation supply and enhance the management and coordination of traffic movement.

- Thus, decreasing overall the conflicts between vehicle movements and reducing the number of the expected traffic accidents.

A study has contributed effectively in this investigation by providing the minimum estimation evacuation time for each evacuation area. It can be determined by dividing the number of vehicles in the evacuation area by the total roadway capacity yields a high-level approximation of the minimum evacuation time of the area [219].

$$T_{min} = \frac{(Pop/AVO)}{R_c} \dots\dots\dots\dots (6.1)$$

Where

T_{min} : Minimum evacuation time, hour

Pop: Population of evacuation area, person

AVO: Average vehicle occupancy, person per hour

R_c : Roadway capacity, vehicle per hour

For example, the Al-Ramadi city has a population of approximately 230,000 people, 30% of people have access to one or more cars; 20% of households have access to one or more cars [210]. The mode of travel is private car and the buses; this will lead to an average 4 people per vehicle according to the high car ownership in the city households.

Therefore, the number of trips needed is,

$$\frac{230000}{4} = 57500 \text{ trips}$$

The population is to be carried by 57500 vehicle trips on the paths that lead to the evacuation areas. Typically, the government has encouraged people to use the public transport mode in order to reduce the chaos condition that can arise in such situations.

There is however a plan in place for emergency events in the Al-Ramadi city that 50% of the public vehicles will be involved in transporting people to safe areas [209]. Since public transportation vehicles have a high passenger capacity, these will be useful in the evacuation process.

Utilizing the population data collected for each evacuation area and assuming average vehicle occupancy between 1 and 3 persons per vehicle, the minimum time to evacuate each area can be calculated.

In case of this city, and in order to evaluate the AVO contribution, we use the minimum evacuation time equation above which has taken the AVO factor into account and estimate the minimum evacuation time. Here, a range of AVO can be applied; between 1 and 3. Meanwhile, we assume different roadway layouts in this evaluation as we have different road types in the city network, as shown in Table 6.9.

Table 6.9 Minimum evacuation time with different AVO

Average Vehicle Occupancy, AVO	Time, hrs				
	Minor Road		Major Road		
	1 Lane C = 900v/h	*2Lanes C = 1800 v/h*	*2Lanes C = 2800 v/h*	*3Lanes C = 4200 v/h*	*4Lanes C = 5600 v/h*
1	255.555	127.78	82.142	54.761	41.071
1.5	170.37	85.518	54.762	36.507	27.381
2	127.777	63.888	41.071	27.381	20.535
2.5	102.222	51.111	32.857	21.904	16.428
3	85.185	42.592	27.38	18.254	13.69

No one can underestimate the importance of this factor in a disaster situation. To help people who have no access to the assembly point or the assembly point is too far from where they are of this time. They are already in the road network when the disaster occurred, to be able to use their private vehicles rather than waiting for the public transportation to carry as many passengers as they can with them to the safe place.

Updating the information about the situation is extremely important to the evacuation strategies and processes. It is important to collect the disaster data periodically; this can be done via VANETs, Cloud computing and other sensing technologies (if applicable and still operational after the disaster hit). In case of testing the AVO value in this situation, applying equation (5.1), and assuming different AVO to different road layout. The result shows that less time is needed to evacuate the vehicles in the case of applying higher AVO on the same capacity of the roads.

The trip generation models have a great contribution to the disaster management system. In the ordinary situation the trip generation models may depend on the land use and the socioeconomic factors but in the case of an event like a disaster the trip generation models may depend on type of population at the time of the event like the home residents, employees, shoppers, people at the hospitals, and people using the transportation network.

Beside all the socioeconomic characteristics have a major effect on the evacuation time, one of the important factors in the evacuation process is the average vehicle occupancy (AVO) which is mainly included in the transportation model and affecting the number of trips required to finish the evacuation process. Our contribution is to study the effect of AVO in conjugation with applying the new communication technology to reduce the delay in the evacuation process and save lives.

6.5   Average delay propagation

The system proposed in Chapter 5 and evaluated in early sections in this chapter is improved and extended in this section. It has been improved by means of introducing a novel message propagation algorithm through VANETs, and the effectiveness of the system was validated by means of extended simulation results (These earlier works were based on macroscopic traffic modelling).

In Figure 6.12, it presents simulation results for the average delay propagation [s] that occurs with V2X, adopted in ICDMS, and the traditional multi-hop technique for disaster management. It verifies the effectiveness of our approach –in terms of a reduction of delay– as compared with a traditional opportunistic networking scheme in VANET.

The Al-Ramadi city is considered to measure the effectiveness of proposing the time message algorithm. Also, the propagation of warning messages from a vehicle near the glass factory is simulated, where the incident happens at 9:00 am. In particular, for ICDMS approach, the following events occur:

(i)   just after the incident has occurred, a source vehicle travelling in the S direction from the glass factory sends a message along on the same direction;

(ii)   at t = 4 sec., the message is propagated multi-hop within a cluster in the S direction;

(iii)   at t = 7 sec., a relay vehicle enters an RSU's radio coverage, and the message is transmitted via V2I to the RSU, until it will be received by other vehicles at t = 10 sec.

A comparison is made for this scenario with traditional opportunistic networking technique in VANETs, where the following events occur:

(i)   just after the incident has occurred the source vehicle travelling in the S direction from the glass factory sends a message along on the same direction;

(ii)   at t = 4 sec., the message is forwarded to a vehicle in the N (opposite) direction;

(iii)   at t = 6 sec., the message propagates via multi-hop within a cluster in the S direction;

(iv)   the transmission stops at t = 10 sec.

For comparative purposes, in the simulation setup we posed parameters according to [214]. We assume the source vehicle is moving at 70 km/h, the inter-RSU and inter-vehicular distance is 500 and 100 m, respectively. Typical message size L = 300 bit, and data rate transmission B = 10 Mbit/s (e.g., for WiMAX connectivity), have been assumed. The inter-vehicle communication data rate has been assumed equal to 6 Mbit/s, while data rates via V2I and I2V are in the range [2.5, 14] Mbit/s.
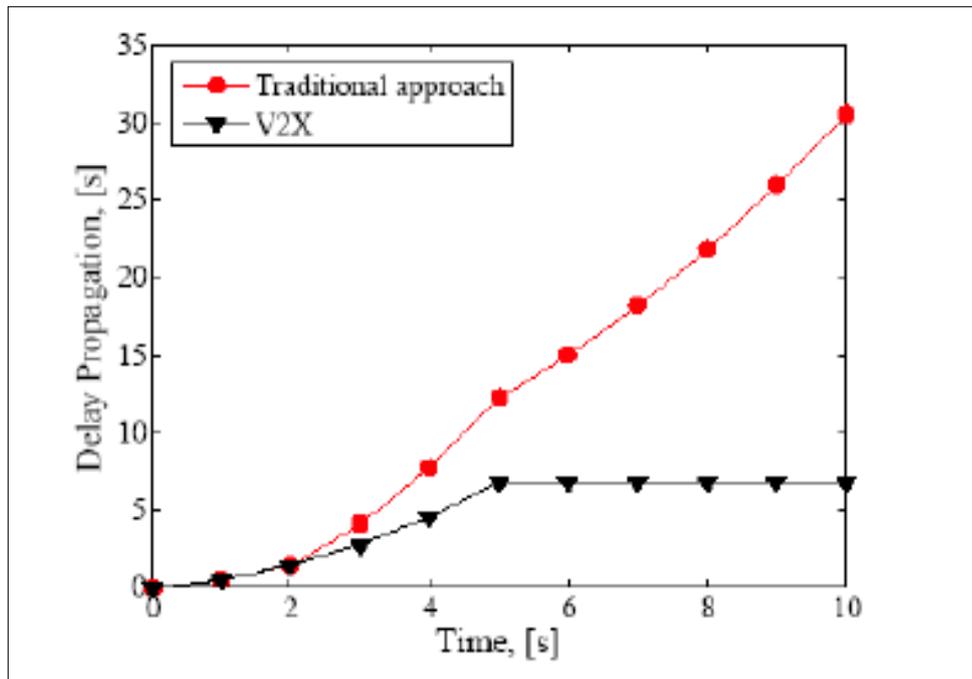
Figure 6.12 Delay propagation in the transportation network of the Al-Ramadi city,
comparison between V2X used in DMS and the traditional approach for disaster scenario

A strong reduction in the delay propagation has been noticed with respect to other forms of
opportunistic networking: after t = 10 sec. from the incident occurrence, the maximum
transmission delay in intelligent disaster management system is 6.81 sec., while 30.45 sec. for
the traditional multi - hop approach. The reduction of delay in intelligent disaster management
system is mainly due to the protocol switching decision of V2X, which exploits high data
rates from wireless network infrastructure.

TRANSPORTATION EVACUATION SIMULATION SOFTWARE MODEL

The emphasis on implementing a disaster management system does not necessarily mean avoiding exposure to disasters utterly, but it could be also designed to minimize/mitigate losses when applicable. On this basis, many emergency evacuation systems have been proposed to warn and evacuate a person, group and community during different threat situations. Meanwhile, prior disaster warning; alerting people in advance or at least immediately before the disaster occurs, would give distinctive and effective results especially in the areas that are susceptible to frequent disasters.

The study concerning disasters and strategies is the first step towards giving the best opportunities to support the concept of disaster strategies management and thus the ability to develop the decision support tools including choosing the best strategy as much as possible for the types available [221] and [101].

In this study, the simulation models approach is exploited, macro-simulation software to evaluate the proposed intelligent disaster management system and micro-simulation software; improving a micro-simulation model via developing a software model, to investigate the proposed system performance on improving the decision for evacuation strategies.

In this chapter, the city model contains the ITS controllers (the in – vehicle sensors and the roadside signs and applications) which pass messages to vehicles in order to help to change the driver's behaviours. Those messages come from the user, via the external SNMP controller. In other words, an external software model has been developed for the aim of this project, it's the ITS controller – where the SPreadSHeet is the user interface of this model. It's the innovative component and it's the one that passes those messages.

Section 7.1 is dedicated to define a wide range of important fundamentals that affect the credibility of the project. Section 7.2 reviews some simulation models that have been developed and used to improve the traffic ability. We present and compare between some simulation models which employed in such disaster management problem. This is to show the features of each model and justify the model selection. Subsequently, we introduce the S-Paramics ITS System features in Section 7.3. In Section 7.4, we describe the development process of the software model for studying urban networks and specifically for evacuation strategies implementing.

7.1   Evacuation strategies model fundamentals

Significant effect of some important assumptions has been revealed and illustrated in this section. Each city model has different characteristics and some of them show significant influence on the evacuation process, and the policy developers need to consider them carefully to produce a robust evacuation strategy policy which enhances the disaster management system effectiveness, the most important factors are:

7.1.1   Transportation modes

Most cities can be classified typically into two major areas, urban and rural areas. Although most urban areas own almost all of the transport modes; buses, trains, airplanes and boats and all are recommended to be available, when possible, in the operation. It is unusual to find that most of these modes have taken part together in the evacuation process [10]. This could be because of the lack of effective connection (even in an ordinary situation). Also, prior organisation between the departments may be necessary. The difficulties of implementing the evacuation plan may include more than one type of them which needs to be pre-installed applications and advance communication equipment, and subsequently need further researches.

Meanwhile, in rural areas and with advance planning, there may be an opportunity for cooperation between local authorities and some means of transport which used for other purposes, including school bus, a private vehicles use of the institutions in addition to some other commercial transport means. For example, in New Orleans in 2005, after Hurricane

Katrina and because of the dense population while private vehicles cannot match the evacuation requirements, the authority prepared a plan which included different transport modes to evacuate those who cannot be evacuated using private vehicles [10].

Also, it is very valuable to assume the buses where could be rerouted for efficient evacuation, and this decision can be recommended by the city traffic authority, where they start to move the people from their position (assembly points) to these areas (EA).

In this analysis, multimodal transportation is considered which serves the network demand; i.e. private cars and buses already exist to take a path from multi origins to multi destinations and the arcs of the network are shared by them.

7.1.2   Evacuation Planning Zone (EPZ)

Most pre-evacuation planning is associated with a well-defined safe area/s called Evacuation Planning Zone (EPZ); where this safe area/s are the planned destination, and the transportation system is involved; traffic roads and highways. This area needs to be relatively easily defined for people.

Modelling different disasters; in the case of disaster scenarios with allocated evacuation zones, has considerably increased, particularly over the last two decades [151]. This includes a range of approaches starting from simple evacuation plans such as evacuation of a group of people on board ship; the number of travellers is known, to sophisticated simulation models, evacuation of large areas; such as metropolitan areas.

In this project, the efficient minimum number and the location of evacuation areas that satisfy demands and capacities (should be able to show the potential of receiving the whole amount of vehicles from the entire network) are determined in advance. Consequently, the important evacuation information could be dispatched to the people such as the nearest evacuation area/s.

7.1.3   Staged evacuation

It has been reported that the micro-simulation evacuation models have attracted few authors to study it, particularly before 1990. To clarify this shortage, it is documented that the task to observe the vehicle as individuals is challenging as well as the lack of providing the advanced software engineering and computer technology.

In our project, we assume that people start their evacuations at the same time so that we avoid some unpredictable hidden problems which may be raised.

7.1.4   Daytime choice

No limits to the time and place can be expected when a disaster occurs. Typically, the evacuation models should be designed to accommodate the traffic management problems such as traffic demand in the worst conditions.

Furthermore, the evacuation plan designer should consider testing the evacuation policy in different times, although various traffic scenarios make the operation; including data collection, too difficult. In spite of that some studies have depicted the importance and difficulties of collecting the related information at different times; such as daytime and night-time population [152] and [223].

Typically, traditional transportation analysis focuses on the classical peak travel demands of the weekday morning journey (home-to-work) and the afternoon journey (work-to-home) trips. Looking at those times when traffic is at the peak times makes sense when seeking to provide acceptable levels of service throughout the day. However, it is crucial to understand that traffic modelling and transportation system capabilities can be analysed within the context of special circumstances such as disasters.

Our methodology and system does not rely on a specific time within a day. In contrast, we consider the peak hour traffic data as an input data to the simulation model.

7.1.5   Public communication and preparedness

Good communication with the public is one of the most important elements of the evacuation, particularly in mass evacuation; this communication can be required significantly pre, during and post disasters [10]. However, most residents listen to one of these available media. Evacuation information is essential to be propagated to different people over different periods, such information is; who, when, where and how to be evacuated etc.

During the disaster, some people are still able to access the information either through different transport modes advisory radio, loudspeakers deployed in the streets or even via the internet if applicable. However, to get real-time traffic information on evacuation routes, different communication equipment is required, such technologies suggested in these situations are the smart monitoring, inter-vehicle sensors and smartphones devices which we seek to investigate and evaluate their important role in this research [15] and [224].

In this research, we place emphasis on effective and reliable communication particularly during the evacuation and this would enhance the safety of people. We exploit the advanced technologies including VANETs and Cloud computing to increase the potential of sending/receiving the information swiftly.

7.1.6   Route choice

In a real evacuation status, to avoid isolation and protection from physical injuries, many studies presented an approach where drivers would choose to follow others; taking the same road chosen by other vehicles. For instant, during the Hurricane Katrina evacuation, the evacuees selected to escape through one road and ignored the other available alternative. Nevertheless, the route choice behaviour in existed new simulation models, such as in S-Paramics and MATSIM, integrated limited driver behaviours. Both MATSIM and S-Paramics offer route choice behaviour known as dynamic route planning (used in S-Paramics for the behaviour of drivers "familiar" with an area) whereas in S-Paramics it sets for the drivers who are unfamiliar with the traffic network existence to take the route, which they believe it is the quickest and prefer the exits linked via major roads rather than the minor roads [225].

In this study, the drivers are able to re-plan their escape routes, factoring in real-time knowledge of the congestion on other roads. Also here, we assume that most routes of the evacuation management are known or can be followed by drivers through some signs can be provided. Also, we consider that the capacity and cost of the paths/arcs are provided. In other words, the size of the network is recognized and the vehicles with satisfy the demand without exceeding the capacity.

7.1.7   Evacuees response

One very important factor can be considered as the backbone of the emergency evacuation and can improve the evacuation process, is the evacuee response, as it affects considerably the evacuation total time.

People who should obey the evacuation announcement, they are called the "evacuees response". The drivers' behaviour is considered as one of the most important factors and should be measured as it reflects the disaster management system success; few current models have studied and considered this factors' influence, and it is not yet presented in the existing state-of-the-art traffic simulation models [225].

During the evacuation time, the drivers vary in responding to the evacuation plans negatively and positively, especially when mass population evacuation has been needed.

The simulation modellers developed the current evacuation models although capturing the behaviour of individual vehicles remains unattainable. In contrast, the combination of the driver behaviour reactions can only be assumed and measured effectively whenever the modellers are able to define the vehicles behaviours as individuals [222].

In this thesis, driver response to evacuation pre-plan is part of our model design. Also, we were able to quantify the driver response, further details will be discussed in Section 8.5.5.

7.2   Evacuation simulation models

As the "reliability of any traffic micro-simulation model depends on the model's ability to produce system's behaviour that is close enough to real traffic situations" [164]. Road traffic micro-simulation software simulates the activity of individual vehicles and their drivers as they move through the road network, further details are defined in Chapter 4.

The algorithms in the model cause each vehicle to react to the presence of other vehicles around it, to adhere to the rules of the road including the active control systems that manage the road and to follow the route that they perceive to be the best to reach their destination.

The cumulative effect of modelling individuals is to represent the road traffic flow on the network and to study the effect of changes in demand on the network, changes in the speed of the network and changes in the management of the network.

The emphasis in this chapter is to examine all three sets of changes under the conditions of an emergency evacuation where the demand on the network will change as evacuees leave the danger area, the speed limit will change as a wide range of speed limitations are used to increase/decrease capacity in both directions.

The project will also examine the effect of traffic management where information is given to road users to affect their behaviour – in lane use, speed control, route choice - with the aim of facilitating their evacuation.

The requirements for a micro-simulation product to use in this project are therefore:

1. That it is possible to change the demand in the model

2. That it is possible to change the link speed by modifying the priorities at junctions, modifying the signal traffic operation at controlled junctions and by changing the speed limits of some road segments.

3. That it is possible to pass messages to vehicles to change their behaviour with respect to their route choice and their driving behaviour.

There are many road traffic micro-simulation programs available from academic research tools to commercial products used worldwide [161]. The academic products tend to be open source and hence may be modified to tailor them to model unusual situations. The commercial products are "black box" in that their source code is unavailable to users of the software and hence may not be modified but they may be open in that there is an API (Applications Programming Interface) or a means of communication within the model to allow users to make their own limited set of changes to the software's vehicle behaviour algorithms or to the operation of the simulation.

The availability of a method of modifying the demand of the road network, and the driver behaviour will be the key in selecting software suitable for this project. The availability of the software and the availability of a suitable calibrated city model to use as a test case will also be taken into account.

Examples about open source projects include SUMO from the German Aerospace centre and MitSimLab from MIT in the USA [161].

SUMO offers an interface to run an external application in synchronization with the simulation and able to modify signals operating on the junctions in the simulation. The TraCi interface was a significant research project to provide the interface and undertaking something important in such problem. However, the major issue here is we might face the risk that the development of the interface would dominate to the detriment of our chapter goal "how effective are the evacuation strategies". Also, we need to implement different modifications to the network traffic system in order to facilitate the evacuation process.

MitSimLab is explicitly designed to investigate the effect of alternate traveller information systems, management systems and ITS strategies. MitSimLab is extensible to include new strategies through significant programming effort adding to the core software of MitSimLab. Using MItSimLab on this project presents the same problem as SUMO, the nature of the project changes from investigation of strategies to implementation of software.

The four main commercial products offer external means which allow a user of the software to modify in a controlled manner through published interface. These interfaces do not provide the full range of potential modification that open source software offers but do present a more task focused means of modifying the simulation [161].

    a. Quadstone Paramics uses a programmers API to allow users to write software in C++ to add functions which modify a driver's behaviour and which modify aspects of the road network.

    b. Aimsun offers a system development kit consisting of software libraries and sample software to allow users to add to the software using Python programming. The interface exposes the driver behaviour model and the signal control systems.

Both Quadstone Paramic and Aimsun present the same problem as SUMO and MitSimLab in that there is a risk the programming work will dominate the project objective.

    c. VISSIM uses a COM interface – a communications tool to expose data objects in the simulation and modify them.

    d. SIAS Paramics uses a message passing interface "Simple Network Management Protocol" (SNMP) to pass data to items in the simulation directly related to ITS and signal control.

The latter two products provide data related interfaces with a user focus in comparison to those products which present software related interfaces with a programmer focus. SIAS Paramics also offers code samples which use a SPreadSHeet interface with Microsoft Excel giving a readily available system to provide the user side of the interface.

7.3   Micro-simulation model: why S-Paramics ITS System

In spite of the traffic network environment is more difficult to be studied due to many challenges such as the size and the dynamism of the network during the evacuation order [226]. It is worth to review the tools which are proposed for static predefined schemes; i.e. the disaster status.

From the operational aspect, to model the transportation system, three practical micro simulation software systems can be considered, they are as follows:

1. CORSIM: This software has been in use since its development in 1970s, and it was designed by the US Federal Highway Administration.

2. S-Paramics: This model has been produced in Britain in the early 2000. It is developed by Quadstone and SIAS Limited. They stated that it is suitable for simulating traffic at the individual level on urban traffic networks as well as regional freeway networks.

3. VISSIM: It is one of the latest micro simulation software developed in Germany by Planung Transport Verkehr (PTV). VISSIM is capable of simulating traffic for multi-modal transportation.

To obtain the effective simulation models at the most close visualisation of field observed conditions, a comparison has been conducted by Choa. He concluded that the results of the most effective are both, S-Paramics and VISSIM models [222]. To enhance the conclusion of Choa, Boxill and Yu supported the study results and recommended that S-Paramics is the better model to simulate a large number of vehicles [227].

Consequently, we select to work with S-Paramics micro-simulation model, for the reasons recorded in this section above and others listed in Section 4.4.3.1 and Section 7.2. To support this decision, they reported that the effective and reliable simulation models should have the flexibility to represent different problems. It should also have the ability to provide the operator's actions such as setting up road blocks or diversions [222] and [225].

The S-Paramics is micro-simulation software that has been introduced in the market since the development of traffic theory, in early 1990 (see earlier explanation in Section 4.4.3.1). Its core activity is transport planning, however it is being extended to be used for evacuation conditions in order to address and adjust the traffic parameters which affect the situation. Using this model has several advantages, the most important of which is the ability to pass messages to vehicles in the simulation by a broadcast device or by information on variable message signs [228].

The S-Paramics ITS system is an "add-on" to the S-Paramics. S-Paramics is widely regarded as a visual micro simulation software package [229], which takes into account the major issues raised during the emergency response. Moreover, the ITS extension allows us to simulate the major management responses and traveller reactions seen during the emergency response. The S-Paramics ITS System enables external software to communicate with a running simulation at pre-determined intervals, to extract data from it, and to adjust parameters within it [230], using an SNMP interface.

The features which can be modelled with the SNMP interface includes bus operations, traffic signal settings, driver behavioural characteristics and vehicle kinematics [228]. Such requirements of this connection are explained below:

- Better signal plans: The existing signal plan language had some known deficiencies, such as no ability to store values. It means a loop measurement from one minute cannot be stored and compared with the same measurement in the next minute.

- Well known systems for implementation: The existing signal plan language is unique to S-Paramics. Giving modellers the ability to use common software programming languages would mean the skills to create the control software would be more readily available.

Initially, we need to obtain geographic and travel data which can be used as input data to the software and then the software simulates the three essential keys build in the software code; lane changing, gap acceptance and car following behaviour, for each vehicle. The statistical output files give the illustration to users to study and understand the traffic network performance. Also it allows the users to investigate more and carry out other researches. A wide range of output files can be obtained from the simulation results, such as queuing length, link flows and link journey time.

The main "alternate option" is to use time periods. In S-Paramics we can change the network at specified times. Typically we use it to change signal times according to a set plan or to switch on lane restrictions, i.e. bus lanes that are only restricted from 6:00 to 9:00 for example. We also can change speed limits and link costs factors. With the demand matrices we can also use profiles to control the release of vehicles in a period to set the rate at 5 minute

intervals. There is also a problem in some traffic networks where the road has a no right turn between 17:00 and 19:00 so we simply changed the junction priorities at a 17:00 time period boundary. The problem was that vehicles were not told to re-route so those that were heading to that junction simply were stuck for 2 hrs.

The ITS controller handles route choice and gets avoids this block. As a vehicle receives an ITS message, it re-assesses its route, this means it is not obstructed stuck if we change junction priorities or close a road completely. Similarly if we just use the time periods, the only route knowledge is that gained from the route feedback mechanism so we cannot give vehicles advice about the problems we predict and they only receive knowledge of what others have seen.

The default route choice method is really just to simulate longitudinal learning for commuters not ITS advice. We cannot alter driver behaviour with time periods. We can adjust headway per link, but we cannot increase aggression to give them that extra bit of urgency in their driving.

Another reason for part of the problem is to use incidents to create a temporary block. S-Paramics has the ability to stop a vehicle or slow it for a fixed time. We use it to simulate things like temporary lane blocks as a van stops for a delivery for 2 minutes or a car have a puncture and blocks a lane for 30 minutes, the problem was that vehicle change lanes to pass an incident.

Due to the problems already identified above, SIAS created SNMP agent in S-Paramics interface to provide the solutions. The SNMP model of a managed network consists of the following elements:

- A space, in this case a simulation, which contains managed objects e.g. signals and detector loops,

- At least one controller to manage these objects

- A protocol for communicating this MIB data, i.e. SNMP

- The MIB and agent are embedded in S-Paramics

Some developers might suggest applying the project objective via S-Paramics software directly. We would report that some parts of it, indeed can be applied directly but with less flexibility, but other parts cannot be implemented unless we need to develop a software model to facilitate evaluating and presenting the system performance in such event. Basically, some reasons, apply restrictions and blocks to individual lanes, were behind writing the SNMP.

As first on the software, S-Paramics can do that but not directly. Here, the underlying communications mechanism is SNMP. In short, the controller option will allow you to do more than we can do with time periods and probably with more management of it as we are just adjusting a controller and can acquire much better visibility and hence management of what we are doing in each run. So far, we have two options to continue this project:

- *Option # 1:* It is to keep editing a model and do this with time periods. For example, split a model into time periods - as low as 5 minutes each period - then you can make changes to link speeds, junction priorities, lane closures etc. The problem is it'll be difficult to manage and not very flexible.

  Also there are problems when time periods change and junction priorities are altered to ban a turn, also vehicles get stuck and so they are not be able to re-assess their turn. The biggest problem here is with the time periods option that we cannot give route advice and cannot have different vehicles react differently.

- *Option # 2:* As identified - it is to use the SNMP system. The first advantage is we have one copy of the model and all the changes are contained in one place, the SNMP controller. It will be a lot less error prone (save a significant amount of mistakes). However the real advantage is we can do more, change things at any time we want and need.

So, we prefer to write an SNMP controller and have it configurable so we have one place for all the changes and we can use all the SNMP ITS features.

7.4   SNMP Interface design

SNMP stands for "Simple Network Management Protocol". It is a mechanism for exchanging information between a manager and a set of managed objects on remote sites. It can be enabled through the S-Paramics license dongle. Basically, the SNMP agent serves data defined by a Management Information Database (MIB) over a network using standard Internet Protocol (IP) communications.

Furthermore, an ActiveX control, known as PController, has been developed by SIAS to enable using of interface by employing Visual Basic (VB). VB was designed by Microsoft in 1991, and it is designed to be relatively simple to use and learn [230].

SNMP provides huge advantages. It manages a wide range of systems and networks which require different management techniques. SNMP has been designed to be used in traffic management through some projects in order to maximize the traffic performance through ITS implementations, and control the on-street hardware such as the traffic signals and loop detectors. SNMP is available in S-Paramics to control the simulation by adjusting signal times and stage ordering in response to loop inputs.

This interface offers the functions required to simulate disaster evacuation and also presents an interface that is usable with standard office based tools without requiring advanced programming skills. The S-Paramics software is also already in use in Salford University and a suitable city model is made available.

SNMP needs two items of information to make a connection: the name of the computer it is connecting to and a port number on that computer [231].

The SNMP interface allows one or more controllers to communicate with the simulation and create links in it to the managed objects. As the SNMP protocol is network based, the controller need not reside on the same computer as the simulation, and multiple controllers may be used. So, all we need is to start up the model and synchronism the actions.

The SNMP interface in SIAS Paramics allows the user to:

- Pass messages to vehicles via ITS controllers to :

- ▪ Modify speed on certain links
- ▪ Modify lane use
- ▪ Modify driver behaviour
- ▪ Give route choice information
- ▪ Change a vehicles car park destination

- • Modify signals

  - ▪ Change stage times on signalized junctions
  - ▪ Change priorities on non-signalized junctions

- • Modify Demand

  - ▪ Turn on or turn off the release of vehicles on a trip
  - ▪ Add new vehicles to the simulation

7.4.1   Activex Control (PControllers)

A controller is "*A software module that communicates with a running simulation reading data from it and setting the parameters of the control measures in the network*" [231]. The "controller" starts the simulation and establishes a connection to it. In this case we call it the external software which provides those messages. SNMP controller is capable to match the entire S-Paramics external interface requirements, and it can be created by utilizing a big set of high level languages readily available SNMP utility libraries [230].

The motive behind the interface was to allow modellers to include active controllers within the simulation and to be able to do this without complex programming of an Application Programmers Interface (API).

It was also important to be able to model these controllers in a standard computing environment rather than write another embedded language to be included in the simulation.

An active controller is one that manages objects such as traffic signals on the basis of information detected in the road network. The controller may be local to a single junction or it may cover a wide area of the road network. There may be multiple controllers with or without coordination acting on a network.

7.4.2   Writing the programme

The usual way of controlling things for the simulated vehicles is to pass over simulated detectors and the SNMP interface passes the information to the external controller. This decides what action to take either by changing signal times or sending messages by an ITS controller in the model.

The interface for the controller is a SPreadSHeet, it is the run sheet to enter the information. It has been written in Visual Basic macro language because it is accessible and it is ideal for interfacing to the dynamically linked library that implements the SIAS SNMP interface. It is also modifiable without the use of any special software tools and the source code is clearly visible, Figure 7.1 shows the SPreadSHeet.

Paramics Model Location	C:\Paramics evacuation\Controller\Demand
Paramics Version	2010.1
ITS Strategies Sheet	Demand_Strategies
ITS Responses Sheet	Responses
Batch or Visual	Visual
Number of runs	1
Number of strategies	10
	Run

Model Time Of Day	07:45:00.0
Model Times Real Time	13.06
Model Number of Vehicles	4775
Active run	1
	Refresh Status

Pause   Restart

FAIL MESSAGES

oops

Figure 7.1 The proposed SPreadSHeet representing the interface to the model

The "Run simulation" button runs the requested number of actions of the specified model and may or may not log data as required. It consists of several of rows, and the simplification of the SPreadSHeet can be seen in Table 7.1. Different versions of this SPreadSHeet will allow different strategy combinations to be tested and the results will be analysed to investigate the effect of strategy choice.

Table 7.1 The SPreadSHeet components

SPreadSHeet components	Explanation
Paramics Model Location	Model location, where the model is stored in the PC. For example, C:\Paramics evacuation\Controller\Demand strategy
Paramics Version	S-Paramics ITS system version. In this study, we use the 2010.1 version
ITS Strategies Sheet	The name of the worksheet with the list of evacuation strategies which are implemented in this study. For example, Demand Strategies
ITS Responses Sheet	The name of the worksheet with the list of response profile
Batch or Visual	Number of the mode. For example, in this study we have the "Visual" mode
Number of runs	1
Number of strategies	The number of the rows in the strategies sheet

The detail of the parameters for each action will vary with each action type, but will be set on the action row in one or more cells. Once connection is established, the SNMP controller creates the links to the objects in the simulation it intends to manage or to use to collect data, and the simulation is instructed to notify the controller. Some internal controllers will adjust signals and others will do motorway congestion management. All can be broadcasted via either pass the messages to vehicles and there can be a road side sign giving the messages as vehicles pass or it can be a broadcast box giving messages to all vehicles. In other words, active traffic controllers receive data from roadside vehicle detectors and use it for example to adjust the timing of signals in adjacent junctions.

A controller may be in charge of a single junction with one set of detectors or it may coordinate the actions of many junctions with traffic flow data received from multiple sources. Typically this is every second for signal control and every minute for less time critical actions. It passes messages to the control devices in the simulation to modify vehicle behaviour, and then instructs the simulation to restart and run to the next controller time step. The data that could be received from the simulation are:

- From loop detectors in the road, split by lane or aggregated for the carriageway

  - Speed
  - Flow

- From signals

  - Current stage
  - Time left in this stage

- From ITS detectors

  - Journey time on a selected path
  - Queue length

- From buses

  - Location of bus

- ▪ Speed of bus

- ▪ Occupancy of bus

- ▪ Time at last stop

- • From car parks

  - ▪ Occupancy

- • From the vehicle releaser

  - ▪ The number of vehicles to be released on a specified trip

The actions that may be passed to the simulation are:

- • To signals

  - ▪ Move to the next stage now
  - ▪ Move to a specified stage now
  - ▪ Change the red or green time for a stage for just the next time it is called
  - ▪ Change the red or green time for a stage for all subsequent calls

- • To flow controlled nodes (i.e. signalised nodes with no prescribed stage structure)

  - ▪ Priority of a turn through the node(Major Medium, Minor or Barred)
  - ▪ Signal state of a turn through the node(Red Amber or Green)

- • To the vehicle releaser

  - ▪ Modify a release rate (takes effect at the next 5 minutes release rate boundary)
  - ▪ Release a vehicle on a specified link for a specified trip
  - ▪ Release a bus on its route

- • The actions that may be passed to an ITS device are

  - ▪ A message to be relayed to vehicles
  - ▪ Which area of influence applies to the message

The ITS device messages are composed of three elements:

- A display message – purely for display and no further details

  - Text
  - JPG image

- An action message – to interpret the display message and provide an action for the vehicles

  - Speed limit
  - Lane restrictions
  - Route information
    - Achieved speed on links
    - Waypoint delay information
    - Car park redirection

  - Behaviour changes (awareness and aggression or a headway modifier)

- A response rate – to describe which vehicles take heed of the message, saying which vehicles will pay attention

  - Percentage of vehicles
  - Vehicles of specified types
  - Vehicles with specified destinations

An example of these messages: we can have a picture of a lorry in a red circle which means a lane is closed to some vehicles, specifically Lorries. Part 1 is the image, part 2 is that it is a lane close and part 3 that only vehicles of types 10, 11 and 12 (i.e. the Lorries) are affected.

In this application, the ITS devices messages are the key element as they control the actions of vehicles moving in the simulation affecting their wider are responses – i.e. route choice and behaviour.

Finally, if a strategy fails, e.g. the junction is not in the model, or the controller does not exist for a reason. Then the fail routine (fail message) is called. This leaves a message on the connection sheet and clears the connection. In short, it calls the process to stop with no attempt at error recovery. As the error is in the input data there is no error recovery strategy to implement other than respond to the message and correct the input.

For example, as one common error can be seen in describing a behaviour is to mistype the link name, i.e. "L1:2, L2:3, L3:4" as "L1:2:L2:3,L3,4" or to specify a non-existent link.

7.5   Evacuation strategies

A number of strategies/actions can be applied and investigated through the SPreadSHeet. In this model, the ITS devices are the key element as they control the actions of vehicles moving in the simulation. We implement two different evacuation strategies in this research, they are defined below, whilst more actions/strategies can be seen in Table 7.2.

7.5.1   Traffic network demand strategy

This strategy is very important for the evacuation operation as we prevent more vehicles to enter the network, we sense the advantages below:

- We reduce the number of vehicles specifically in critical zones which already have been affected considerably due to disaster. The vehicles is prevented to enter the traffic network and hence lead to huge advantages include giving time and space for the vehicles which they are already inside the network and then the last can receive the orders of the evacuation operation and leave quickly outside the network.

- Majority of street flow is improved and increased.

- Speed improvement can be obtained.

7.5.2 Traffic network speed strategy

Speed strategy considers one of the important evacuation strategies. It is "*Modify the speed limit on a set of links*". We are able to set different speed limits (increase or decrease limitation) to encourage the driver within different location to move/escape from the disaster area as well as delay others to reach their destination through the disaster area.

Table 7.2 Evacuation strategies

Evacuation Strategies	Description
Signals	Set a red or green time on signal stages. i.e. to close a junction; coded it as a signalised junction with a normal stage and a closed stage. Code the junction such that the closed stage is never active as the model runs. Then as required, call the closed stage through the SPreadSHeet
Route	Either link or waypoint oriented, vehicles are given information about the delays on a route and will re-route accordingly. To use the link version a speed is allocated to a set of links which overrides the achieved speed seen by familiar vehicles in the route calculation
Lanes	Modify the lane use, i.e. open the hard shoulder which would be coded in the model as a normally restricted lane
Redirect	Direct vehicles going to a particular zone or car park to go to another one. The model need to be coded with the destination zone linked to a set of car parks and these are used as the stopping point

SOFTWARE MODEL: RESULT, ASSESSMENT

AND DISCUSSION

The Disaster Management System is defined as "The implementation of plans, the use of the personnel and equipment to achieve the tactical and task requirements of a response to address a given threat" [70]. Typically, the emergency evacuation includes the range of activities that can be represented by the integration of intelligent technologies, applications and strategies which are used within the disaster management system in both scenarios, before and after disaster strikes, in order to mitigate the damage.

In this chapter, we employ the S-Paramics ITS System controller and demonstrate the city X information to investigate the proposed intelligent disaster management system impact on the evacuation strategies performance. Also, we consider two different transportation evacuation strategies; they are Demand and Speed strategy, to find out which strategy has more power in such situation. In addition, we assume both strategies in two scenarios; scenario 1 for each isolated implementation and scenario 2 for both strategies simultaneously.

This chapter is organized as follows. Section 8.1 provides a description of the smart cities as the study objective is to increase the safety and traffic system performance and we consider this goal as an essential for the future cities. Section 8.3 gives the definition for some important input data that are considered while we apply the developed model. Section 8.4 proposes various disaster and the evacuation scenarios implementations, and finally provides an evaluation for the system.

8.1   Smart Cities

A Smart City can be defined as "A city that meets its challenges through the strategic application of ICT goods, network and services to provide services to citizens or to manage its infrastructure" [232]. Smart-X has become one of the most commonly used terms in different aspects. Smart-X could refer to: Smart City, Smart Transport, and Smart Technology

including Smartphone. Also, for diversity purposes, other terms are used in different resources such as intelligent and innovative [232].

Smart city depends primarily on providing the information and communication technologies and services to be available to the population through web access services for both personal and business use.

In addition, the transportation network based evacuation operations include a range of activities that can be represented by the combined operation of smart mobile technologies, applications and strategies. Consequently, the evacuation planning has been given considerable attention over the last decade.

To build or transform to a smart city, governments and different agencies must start to place emphasis on increasing the penetration of the ICT technologies while they contribute effectively to enhancing economic growth. Meanwhile, promoting innovative cities with sophisticated technology, is crucial and considered essential for establishing efficient management systems [233].

8.2   The disaster problem

In this chapter, we will introduce the disaster problem management from a different perspective, although we still consider a dynamic traffic network exposed to a disaster in a particular area within the network and there is a decision to employ our intelligent disaster management system to evacuate the people through different links. This involves the shortest path and quickest time to specific safe evacuation areas selected in advance which supposed to accommodate the infinite amount of flow. It also involves implementing some other transportation evacuation strategies.

In this chapter, the evacuation strategies do not necessarily just mean evacuating people to a safe area, as we proposed and evaluated in Chapter 5 and Chapter 6, but it also means controlling, manipulating and guiding people so that they do not go towards the dangerous area.

8.3   Simulation model configuration

The evacuation management is one of the critical processes during a disaster. In disaster scenario, a particular area within the traffic network is exposed to a disaster and there is a decision to evacuate the people. To achieve the objective of this proposal, implementing a reliable and smooth evacuation plan, we develop a model to present different evacuation strategies and we will discuss the results to obtain and effective decision and hence save people.

For this end, we employed a micro-simulation model called S-Paramics ITS System, which is discussed in Section 7.3, to simulate the problem and present the best combination of the evacuation strategies.

In a normal life scenario, the vehicles have their destination preferences from the respective origins. In a disaster situation, the chaos status is set and the vehicles become blind with no information and the number of evacuees often far exceeds the route capacity, i.e. the number of vulnerable people who need to be evacuated from the disaster area is higher than route capacity design in a unit time, so there is an important link between the mass evacuating demand and the relatively scarce transportation supply. As a result, the intelligent technologies (as mentioned earlier) will be exploited to control, manage and guide the drivers to the safe areas. To this end, we exploited the emerging ICT technologies in this problem including VANET and cloud computing as discussed in Chapter 5, for further information, please visit [15] and [224].

In disaster scenarios, most of the communication media become saturated due to many factors such as unpredicted increase in demand as many people warning other people inside the disaster area or their relatives outside the area, make huge pressure/demand on the cellular network.

In addition, communication infrastructure could be exposed to damage, resulting in chaos since drivers are starved for information. Also, different emergency rescue teams are keen to use the communication devices to work cooperatively.

The important data required, either to use them as input files or to estimate other conditions, can be divided into several groups, we will explain them below:

- Some static variables contribute to identifying the level of the situation, most important are the scale of the disaster, the position of the disaster, if there is an alarm in advance, the familiarity/awareness of the community to these kinds of disaster etc. Apart from these assumptions, Section 7.1 illustrates the other most important major factors that influence the whole evacuation operation.

- To use the simulation model, some important entry variables relating to the transportation system are vital to be collected and should be available to represent our case, such as geometric design, vehicle type, flow, speed etc. all are depending on the situation.

- In order to investigate the evacuation implementation time for the people to move from different zones to safe areas, we need to define the disaster area which has been affected by an event [222]. It is crucial to provide the basic information for the evacuation models such as; when the evacuees have to start the evacuation process and their safe destination (EPZ).

Finally, in this study, we assume the number of the evacuation areas that are prepared to receive the whole number of vehicles. Also, the location of the evacuation area is named in advance. We will assume a wide range of time periods to evacuate drivers which exclusively show the considerable contribution of our model involvement and eventually our proposed system.

8.4   Smart evacuation scenarios

The basic components of a city transportation network are depicted in Figure 8.1; they consist of zones, nodes, and links. To investigate the proposed system influence on the evacuation strategies, the network may be built to represent a specific city area with recognizable junctions and road links, or it may be an abstract network such as in Figure 8.1.
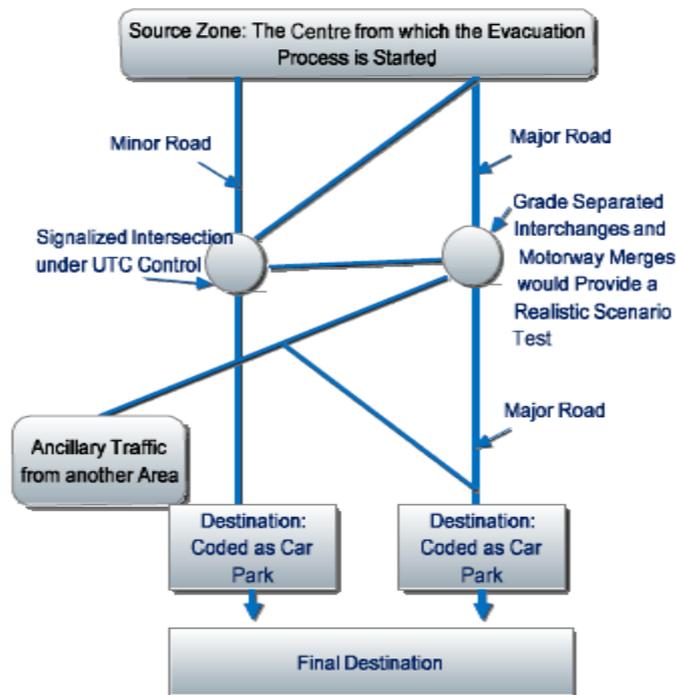
Figure 8.1 Transportation network component of a city

However, in this study, a real city network data is used; we refer to it as city X. This city is located in the United Kingdom and comprises more than 25 zones and more than 300 nodes, each node carries different characteristics, such as the type of traffic control, while links carry the characteristics of traffic and geometric design (e.g. speed, visibility, directional movement, etc.). Figure 8.2 presents the transportation network of the city X in base situation.
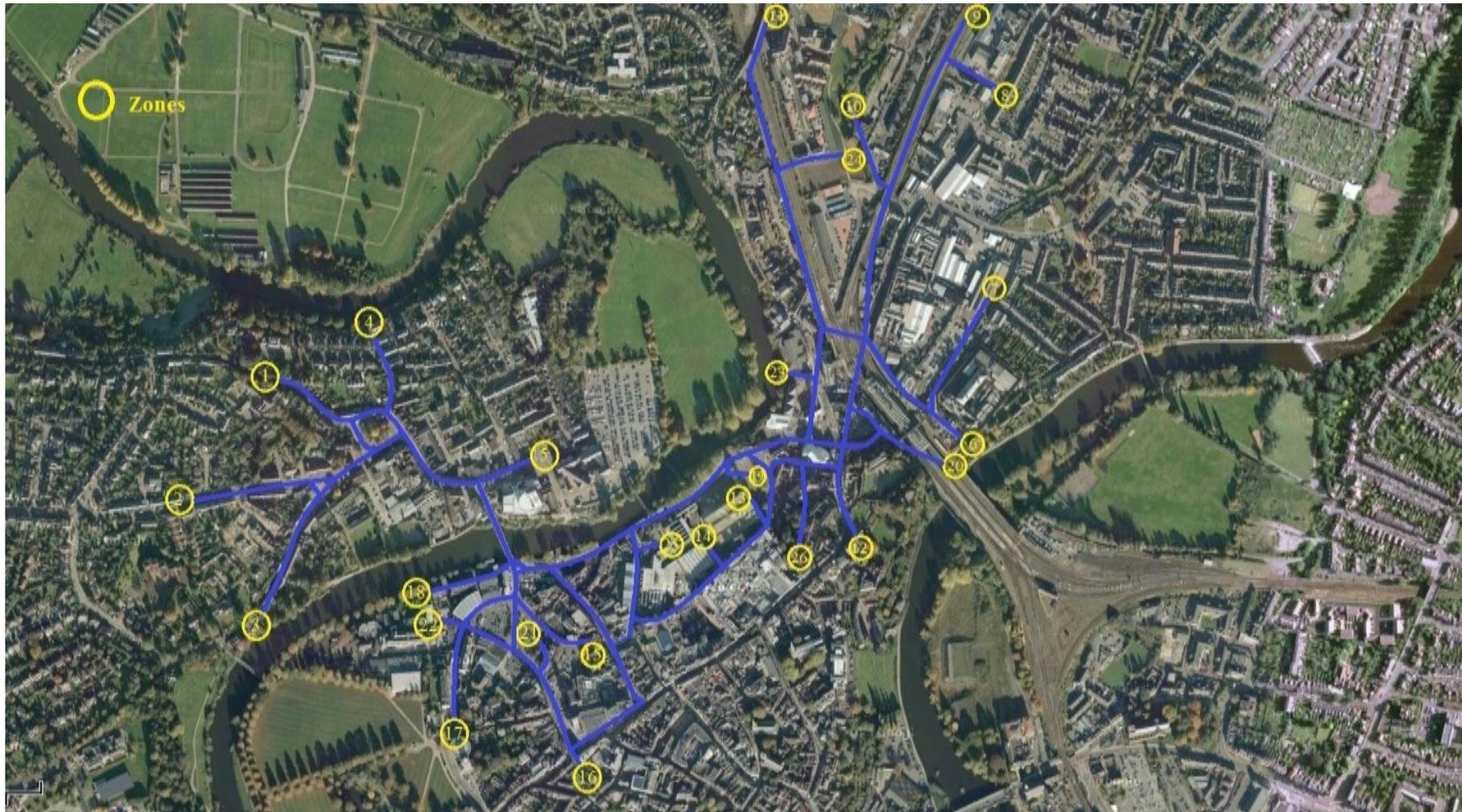
Figure 8.2 City X transportation network in base situation

From different accident potential risks; natural and man-made, different potential risks for disaster scenarios can be predicated such us technology failure due to shutdown of power plants that feed the city, we assume the city is affected by the explosion of hazardous materials (for example) which requires a swift response in the form of a pre-planned range of evacuation strategies.

In this study, for this city, we have tested many disaster scenarios; assuming that a disaster hits different areas and causes the chaos situation. We duplicated the disaster scenario over 20 times throughout the city to find the worst disaster damage results; the undesirable circumstances caused by a disaster. To determine the worst disaster, we focus on more congested links which represent the lowest rate of flow, increased vehicular queuing, for the entire network with the potential of having a huge number of vehicles that are prevented from going out towards the network due to congestion and even many blocked links, when vehicles are stationary for periods of time, also known as a traffic jam. Also, it could be recognized by slower speeds, longer trip times.

Figure 8.3 represents the snapshot for the city X while different six disaster scenarios are applied. Usually the most critical conditions within the traffic network is during the traffic peak hour as rush hour represents the maximum number of vehicles moving across the entire transport network, as we are able to test the model in the worst conditions, thus enabling us to suggest appropriate strategies. In this city, the peak is in the morning period between 8:00 - 9:00 am. We consider that the incident hits the city at 8:00am, i.e. with the beginning of the peak hour.

Table 8.1 shows the results of different disaster scenarios that have been tested to determine the worst scenario. Meanwhile, we pinpoint the links that have been affected; such as oversaturated flow, the chaos, and confused driver behaviour and aggressive.

Table 8.1 is created based on using the computation model; S-paramics ITS system integrated with the developed model, see Appendix A for more examples.

Table 8.1 shows each disaster scenario details; how many nodes involves in the affected area and how many links are blocked.

Some disasters affect less number of links and nodes, however it doesn't indicate that they are less damaged as they related to other factors such as the utility of these links, how many vehicles go to their destination via these links etc.

Table 8.1 An example of different disaster areas

Disaster No.	Nodes	Links blocked by a disaster, each link in both direction
1	11, 77, 104, 76	11:77, 77:104, 104:76
2	40, 83, 46, 89, 90	40:83, 83:46, 46:89, 89:90
3	34, 35, 148	34:35, 35:148
4	21, 142, 20, 121, 122, 135	21:142, 142:20, 20:121, 121:122, 22:135
5	19, 53, 143, 20, 121	19:53, 53:143, 143:20, 20:121
6	141z, 80, 31, 79, 23, 19, 26, 56, 25, 24, 144z, 21	141z:80, 80:31, 31:79, 79:23, 23:19, 19:26, 26:56, 25:26, 25:24, 24:144z, 144z:21

After defining the disaster area, we apply the disaster on the selected area 3 times to ensure that we have the crucial conditions and this area needs to be controlled and then we calculate the average of the 3 scenarios. Operating and duplicating the same model for many times will assist to recognize the critical zones.
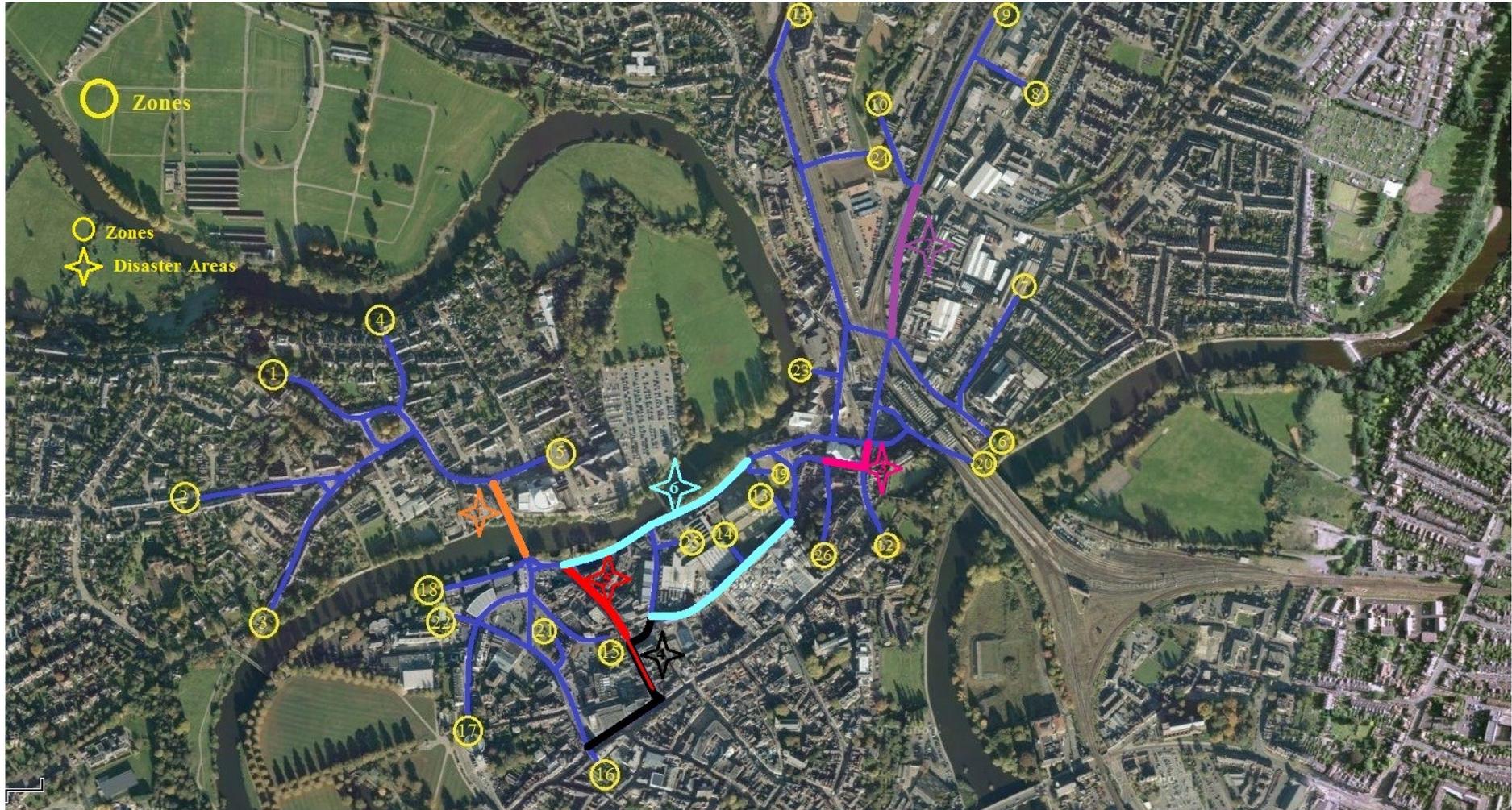
Figure 8.3 An example of some different disaster areas

Figure 8.3 shows the different disaster area selected randomly as listed in Table 8.1. We notice that event affects some zones while others are not affected that much, this could be because of the below reasons:

- The event could block some arterial roads which are considered one of the important traffic road combinations and are expected to accommodate high number of vehicles.

- The event could block local roads, however they are linked to major/arterial roads and zones.

- The events might block the only alternative streets that lead to busy zones/links, or could block the exit of busy zones/links.

However, some are not affected by the event or even can adapt to the situation, because:

- The zones are not busy in a normal scenario.

- The location of the event to this area is far enough to send the vehicles to a safe area or their original destination early.

- The peak time of sending/receiving vehicles could be before event time or behind the event time, enough for vehicles to move between.

- Alternative roads are available.

Additionally, some other crucial issues have been taken into consideration when we select the worst disaster area, although it should cover the whole transportation network:

- As it is the peak hour, most zones already have started sending and receiving a large number of vehicles, so the vehicles come through different network links, see Table 8.2. The table provides an example of the number of zones that have been affected by the serious disaster. However, different starting times are spotted between different zones during the peak hour.

Table 8.2 An example of the unfavourable cluster zones

Disaster no.	Zones affected by the disaster
1	1, 2, 3, 4, 5, 7, 9, 11, 16, 17, 20, 21, 22
2	1, 2, 3, 4, 5, 11,16, 17, 21, 22
3	1, 2, 3, 4, 5, 7, 9, 11, 16, 17, 21, 22, 24
4	3, 9, 11
5	3, 9, 11
6	16, 21

It has been noticed in Table 8.2 that there is a discrepancy between the number of affected zones and this eventually affects the total number of vehicles. It ranges from a few zones to a large number of zones. However, it does not indicate that few zones affected means little damage caused. For example, disaster no.4 and 6 was the worst disaster area although few links are blocked. The interpretation of this phenomenon is that the zone location and size is crucial within the network.

- Also, Table 8.3 presents an example of some major zones where a number of vehicles have not been able to leave their original zones towards the network in different start times, and this considers one of the most important reasons behind the area selection. In addition, we consider which zone is closed first as it varies between zones according to its location from the event area and how many of the vehicles may send or receive daily in normal mode (i.e. is it a major or minor zone).

Table 8.3 An example of the important disasters

Disaster no.	Zones affected by the disaster	Start time of blocked zones, am	The network is blocked entirely, am
1	1	08:03	08:38
	2	08:02	
	3	08:05	
	4	08:06	
	5	08:09	
	6	08:24	
	7	08:04	
	8	08:05	
	9	08:16	
	10	08:18	
	11	08:17	

- Temporary congestion in zones has been raised, during the investigation of the worst disaster area. We noticed that number of vehicles started to aggregate in some zones and then they were released after a while (sometimes before the peak hour ended). However, it is crucial to focus on this point and consider it even it does not affect the situation in our scenario as it causes serious impact if it is ignored and could cause a second disaster.

- Meanwhile, the start time of the vehicles which have been prevented from going outside due to the traffic jam (compulsory not optional), all can be seen in Table 8.3.

- Finally, for how long is the traffic able to move around (even badly; some traffic are still capable of moving around but at a slow speed with long delays etc. Furthermore, some major zones are still able send/receive vehicle even not in same normal mode and takes time to be stopped.

We need to mention a very important issue. We are not underestimating the minor damage caused to the city but we need to investigate the worst case so we will be able to establish the importance of our proposed system and its application under the worst conditions.

In this study and from Table 8.1, disaster no. 1 was the worst disaster scenario that hits the area and causes the devastation conditions. The disaster divided the city into two major sub-networks, upper and lower parts.

Now, Figure 8.4 shows the transportation network after the disaster hits the city X. At this stage, the worst disaster area reflects more congested links and represents the lowest rate of flow over the entire network potentially resulting in a large number of vehicles being prevented from entering the networks.
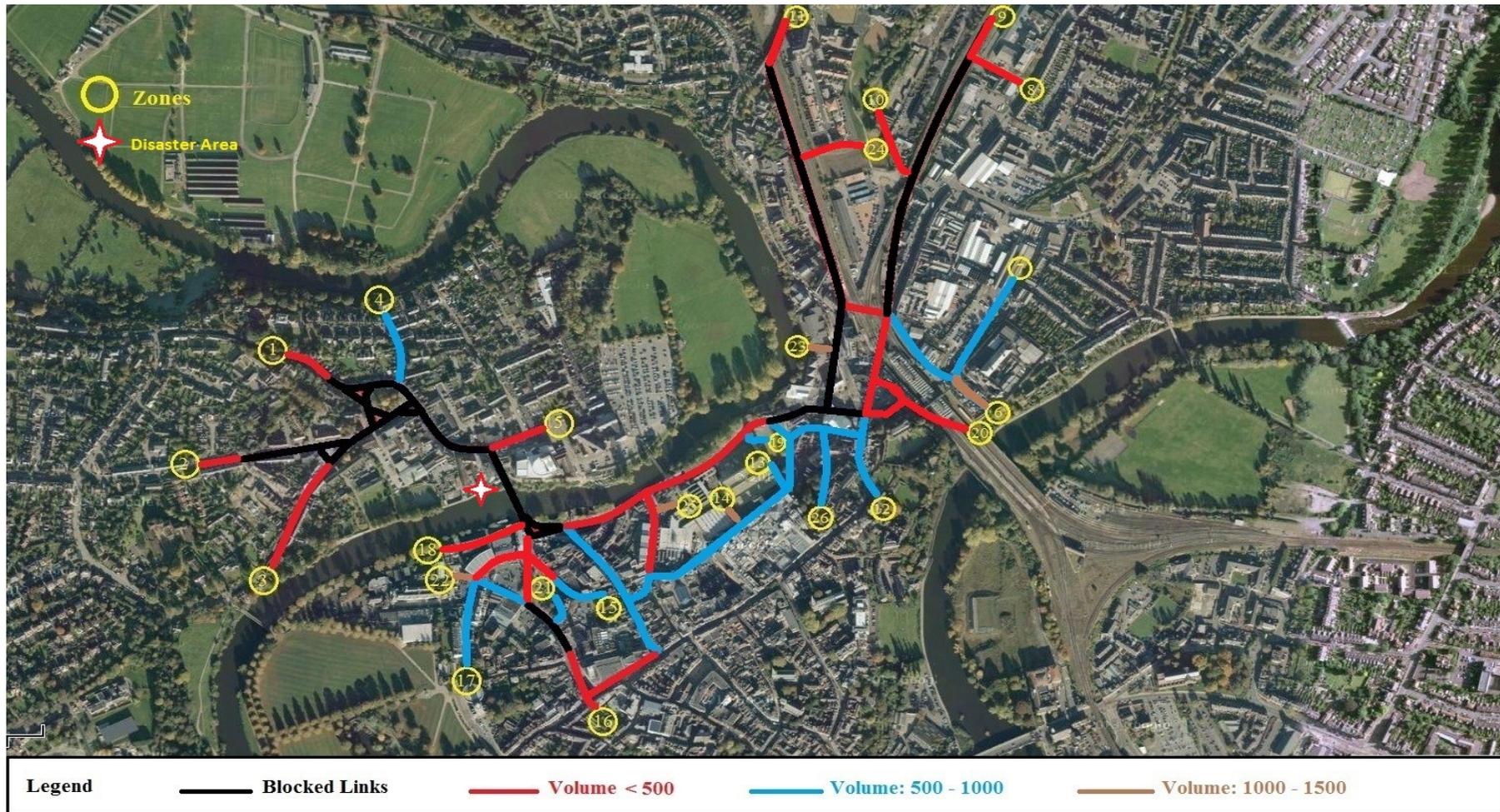
Figure 8.4 The transportation network after the disaster hits the city X

Most of the upper part streets are blocked (depicted by the roads coloured in black). In addition, some streets have very low volume, below 500 vehicles per hour (depicted by the roads coloured in red). Also note that the roads connecting the disaster area with the zones located in the lower part of the city have very low volume, coloured in red, accompanied by a couple of roads which have volumes between 500 and 1000 vehicles per hour (represented by roads coloured in blue).

Figure 8.4 shows examples for different areas of the worst accident. It can be illustrated as follows: after a short time, in our case less than 5 minutes, the event causes the network to be closed in many zones and the flow rate has become too low, i.e. vehicle speed is dramatically decreased and some links become blocked or damaged sufficiently to cause slower egress rates. At the same time, a large number of vehicles have begun to accumulate in many roads especially the links nearby the event area or stack in the original zones.

Table 8.4 An example of different zones showing the accumulation of number of vehicles at disaster scenario

Critical zones	No. of accumulated vehicles
1	310
2	477
3	377
4	48
5	59
6	16
7	696
8	249
9	645

A wide range of transportation evacuation strategies can be applied such as Demand, Speed, Lane Reversal and Redirect movement destination, see Table 7.2. In this study, we consider two different evacuation strategies, Demand Strategy (DS) and Speed Strategy (SS) to be isolated employed and simultaneously; other evacuation strategies can be applied and evaluated in future work. The emergency response system including DS & SS will be discussed and evaluated next.

8.5   Smart evacuation strategies: implementation, result and evaluation

In order to examine a broad scope of possible evacuation outcomes for the city X, multiple evacuation strategies can be applied and modelled. In this work, we apply two different evacuation strategies, and we evaluate the success of implementing the strategy on the entire network. Subsequently, we either continue the processes or perhaps there is a need to change the strategy where applicable and appropriate.

In other words, after propagating the evacuation strategy, we assess the traffic situation and observe the effectiveness of the disaster management system on the network by comparing the performance of the proposed system against the traditional system.

8.5.1   Demand strategy implementation, DS

After the incident hits the area, our intelligent technologies have recorded an obvious problem, as we have expected in Chapter 5 and 6, a huge number of vehicles is accumulated inside many zones. As a consequence, it increases the risk of being trapped as the majority of vehicles will not be able to leave the network quickly according to the evacuation plan. Here, demand strategy is suggested to be employed which means stopping people from going towards the entire network including the disaster area. Typically, the strategy is imposed on some zones and people are prevented from going out in order to reduce the entire network congestion.

The S-paramics model is able to show the critical zones that suffer from the disaster, at the same time with the chaos conditions that have been generated in the whole traffic network itself. Stopping people from going towards the network would increase the potential of causing less congested links and increase the vehicle's safety.

Hereby, we employ the designed model via the user interface; SPreadSHeet, to monitor these zones and implement the demand strategy, see Table 8.5.

Table 8.5 gives an example of some affected zones where the demand strategy has needed to be employed (stop sending vehicles to the entire network) because:

- It is difficult to control/stop some groups aiming to go via the event area or to critical zones.

- In addition, it will be more flexible for other strategies to be implemented.

- As it is difficult to have a picture of the total damage, it will be safer to keep the vehicles in their zones once they are in zones where they are secure.

Table 8.5 An example of demand strategy worksheet input data

References	Evacuation strategy start time,	Evacuation strategy end time,	Strategy	Matrix	From zone	To zone
					9	1
					9	2
					9	3
					9	4
					9	5
					9	6
					9	7
					9	8
					9	10
					9	11
1	08:05	09:00	Demand	1	9	12
					9	14
					9	15
					9	16
					9	18
					9	20
					9	21
					9	23
					9	24
					9	25
					9	26
					14	1
					14	2
2	08:30	09:30	Demand	1	14	3
					14	8
					14	9
					14	11

In this strategy, various crucial input data have been considered in the demand worksheet in order to present the considerable proposal system influence and compare the results to other traditional systems. As mentioned earlier in Section 7.2, the significant participation through this model is the alternative option which means the use of time periods. We introduce different input start times and time intervals. For example, scenario no.1, 08:05 - 09:00 am, represents employing our proposed disaster management system as we detect the event very early and are able to propagate the transportation strategies quickly, while scenario no. 2, 08:30 - 09:00 am, represents the traditional disaster management system as it takes time to announce the event and recommend the evacuation plan.

Column 6 shows the number of different city zones while they suffer from the event and need to consider the demand strategy, stop the vehicles from going towards the network, different other zones. Column 7 gives the number of zones that shouldn't receive vehicles (as in normal scenario) from zone mention in column 6 same raw.

8.5.2   Demand strategy: results and conclusions

The results of applying the DS for the entire traffic network and check the traffic situation every 10 minutes; because we have the intelligent disaster management system which enables us to respond to the disaster quickly. In other words, Table 8.6 demonstrates the improvement to the network after applying the DS. When utilizing the new system; we have applied the DS immediately after the disaster hits the area (because we benefited from the existence of the intelligent disaster management system), after 5 minutes; 8:05 am, we can see the improvement in the number of the vehicles in each critical zone. In contrast, the traditional system participation is seen when we apply the DS while we rely on the traditional disaster management system, so there is a delay in receiving and dispatching the disaster information. As a result, the vehicles keep entering the network, causing congestion situation. To sum up, Table 8.6 shows a further increase in the number of vehicles saved, by up to almost 50%. The comparison between both scenarios shows that we are able to secure more of vehicles, up to double the number, and hence improve the network performance in terms of safety.

Table 8.6 An example of the demand strategy implementation results

Critical zones no.	No. of accumulated vehicles during the disaster, veh.	No. of accumulated vehicles while applying DS for one hour, veh.	
		Traditional systems scenario	Intelligent system scenario
1	310	384	516
2	477	560	781
3	377	457	603
4	48	55	74
5	59	69	96
6	16	21	29
7	696	780	905
8	249	376	666
9	645	764	870

The huge improvement in the number of accumulated vehicles in each critical zone can be seen clearly in Table 8.6. Notice that, the improvement has included both kind of zones; high and low volumes of accumulated vehicles such as the difference between zones 7 and 6 respectively, and in both scenarios; traditional and intelligent disaster system. The key force of employing the demand strategy is to improve the situation by decreasing the traffic supply and hence avoiding the involvement of as many vehicles as possible in this problem.

Furthermore, to increase the chance for other vehicles which are already inside the traffic network to escape swiftly from the serious event, we improve the traffic flow and balance the use of traffic resources. Please see Figure 8.5. Also, we give an example of the traffic network volume in different disaster situations, while using traditional technologies and intelligent technologies situations, all in Table 8.7.

Table 8.7 An example shows the no. of vehicles in different links in city X in different statuses

Link name	No. of vehicles, veh/hr		
	Disaster status	Traditional system status	Our proposed system status
0 - 62	156	204	290
62 – 65za	160	156	258
65za – 09	480	548	738
09 – 72	244	272	462
72 – 47	72	76	170
47 – 112	72	76	170
72 - 06	388	420	546
09 - 105	480	492	690
105 - 76	480	482	696

As it is depends on each city's characteristics and no. of vehicles volumes, here, it is important to mention that the legend in the figures, Figure 8.5 & Figure 8.6, shows different link volumes as we fractionate the volume into small volumes. In other words, we choose to use a different legend than used previously in this thesis, Chapter 6, just to ensure that the improvements have been presented clearly.
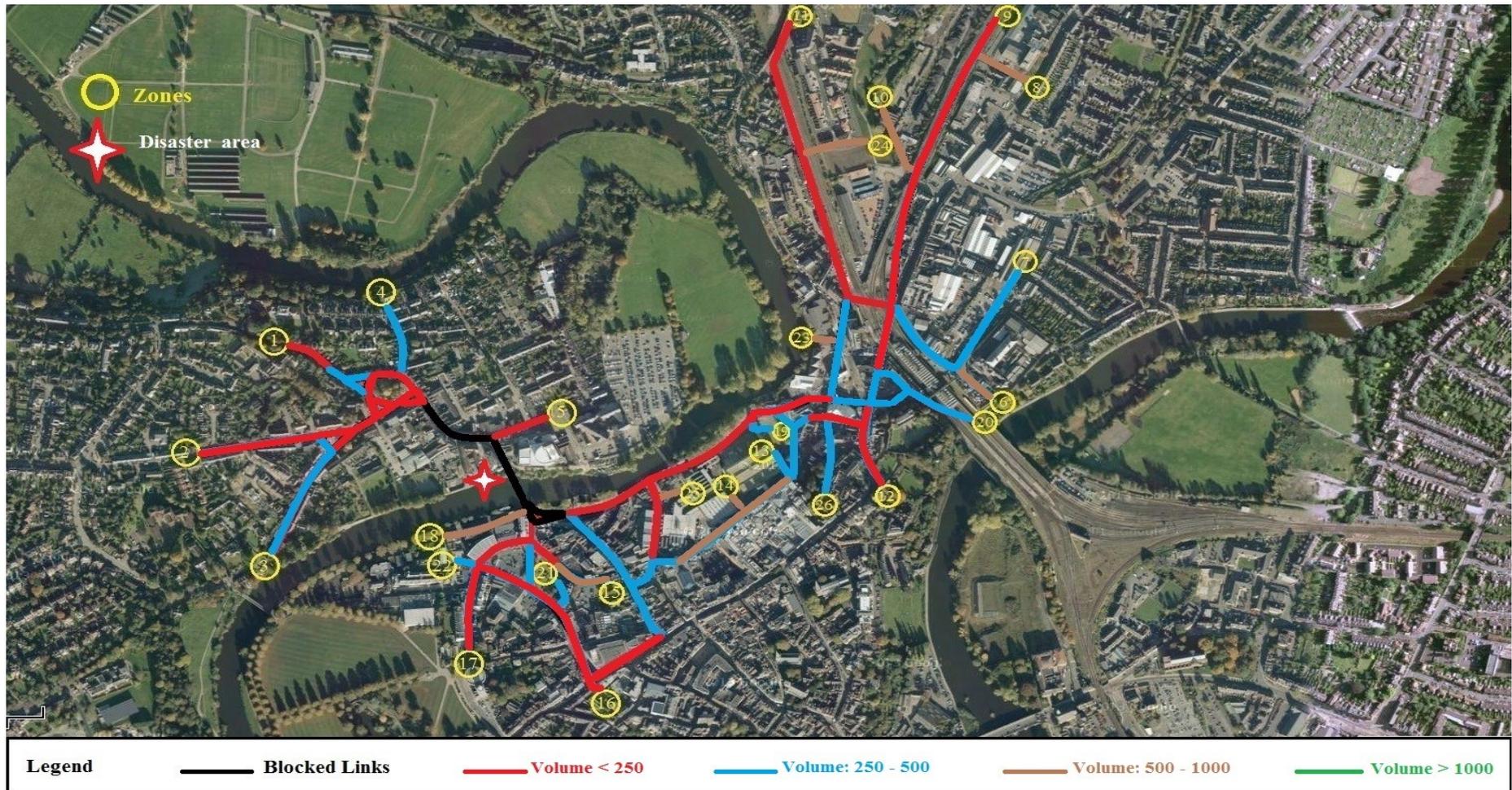
Figure 8.5 The transportation network of the city X while using the demand strategy, traditional management system

Figure 8.5 shows little improvements to the whole network which involves, as in this status, transform few links from black colour, blocked and speed is zero, to red, volume less than 250 vehicles per hour. Meanwhile, many major links are still block (black or red) which affects considerably on the disaster transportation evacuation strategies performance and subsequently on the disaster system suggested.

Furthermore, the rest of the network consists of just links of blue colour, which have volume between 250 - 500 vehicle per hour, and links of brown colour, which have volume between 500 -1000 vehicle per hour. In other words, the vehicles movement of entire network indicate that most vehicles are not moving in a way that we seek.

While Figure 8.6 represents the huge improvements that have been achieved during the implementing of the intelligent disaster management system and its applications, intelligent evacuation strategy. The figure shows one black link which represents the disaster area and it is difficult to clear. A few red links are still in the figure while most links turned to brown colour with volume more than 1000 vehicle per hour. Also, many green links are appeared in this figure which mean the successful and application of the strategy usage.
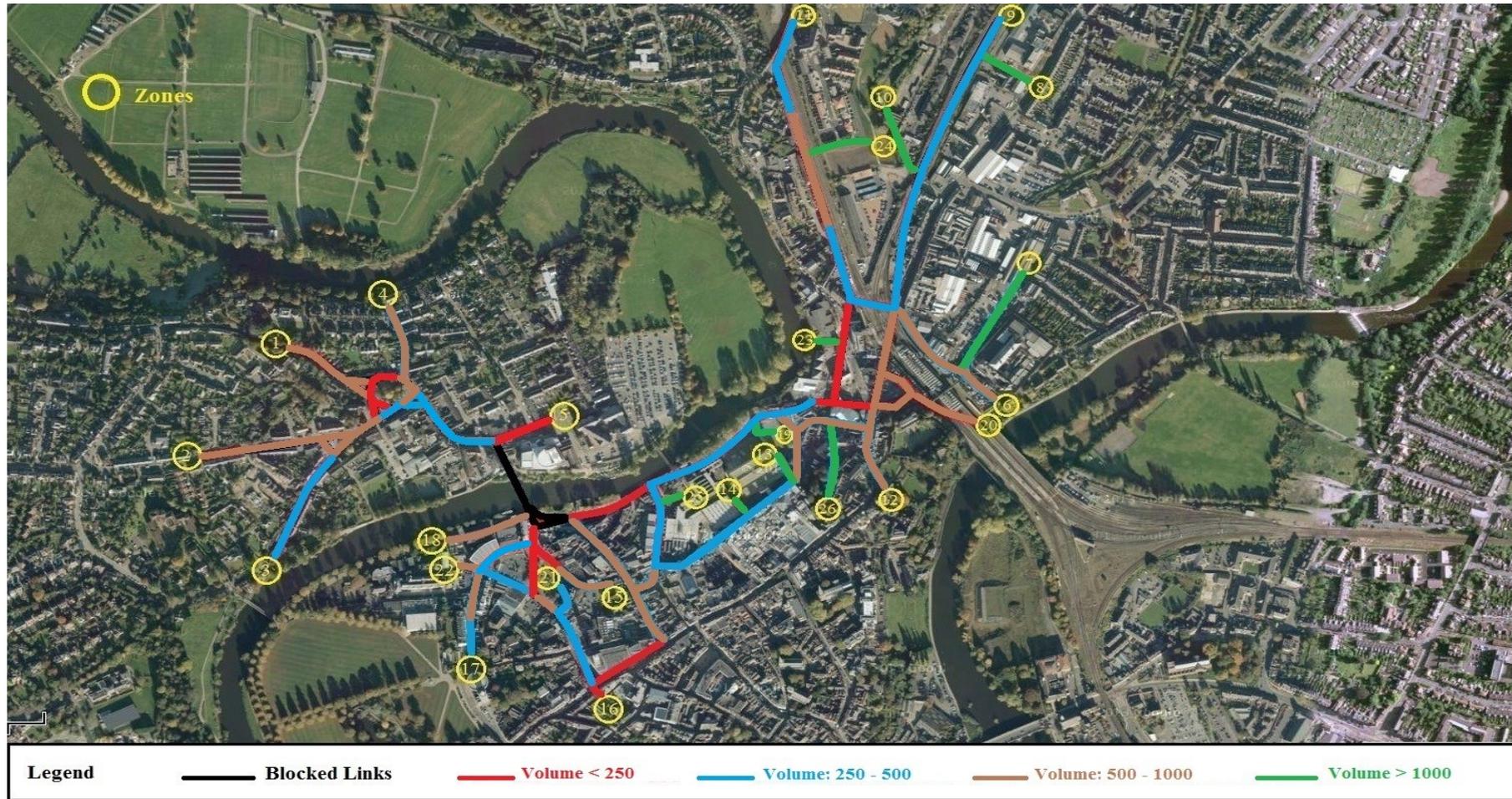
Figure 8.6 The transportation network of the city X while using the demand strategy, our proposed disaster management system

8.5.3   Speed strategy implementation, SS

The second evacuation strategy which has selected to be implemented in this study is the Speed Strategy. In early work, we have proposed and evaluated an intelligent disaster management system based on the emerging ICT technologies such as Vehicular Ad hoc Networks (VANETs) and Cloud Computing with a focus on transportation in urban environments, see Chapter 5 and 6. To continue this effective contribution, we have developed a model to examine the proposed intelligent system performance in improving the transportation evacuation strategies, see Chapter 7. The Demand Strategy (DS) has been shown and examined as one of the important evacuation strategies to measure the improvements, see Sections 8.5.1. Now, we applied and evaluated another transportation evacuation strategy called Speed Strategy (SS), independently for the whole traffic network. Meanwhile, the driver response to the emergency situations and their behaviours in travel choices may be difficult to quantify theoretically, however, driver response to evacuation pre-plans is part of the model design and we present the importance of this fundamental key through various evacuation strategies, more details will be presented in Section 8.5.5.

In the case of using the SS, a wide range of conditions can be applied. For example, we are able to increase the speed limit for all critical links as we aim to facilitate the escape from the disaster area as quickly as possible, and/or slow the speed for other links to prevent vehicles moving towards the disaster area, the dangerous area and other affected links, see Table 8.8. The table shows the important speed strategy conditions could be implemented.

Table 8.8 Speed strategy sheet, example of various conditions

Strategy start time, hh:mm	Driver response, %	Speed range limit, mph	
		Increased /	decreased
08:05	25	40	5
08:15	50	50	10
08:30	75	60	
08:45	100	70	

Although speed limitation selection is done according to the transportation situation, it depends on some other elements such as network geometric design, motorway arterial to a major urban network. This is because if we choose the wrong speed, then we can expect a short term accident (secondary event) which will definitely increase the chaos and cause more damage and importantly make the strategy implementation more difficult. Thereby, we decide to choose an acceptable range of speed, low and high speed, which suits the situation.

Also, from an analysis perspective, we are able to enter different start and end strategy implementing times which represent the disaster management system's main contributions. In other words, it shows the advantages of our proposed disaster management system over the traditional system. Meanwhile, we could control the duration of each scenario depending on the real-time data received from various communication technologies including VANETs.

In addition, driver response is considered and quantified in this study for the first time. Four different percentages are used in this research to present the importance of this element as it speeds the evacuation operation, however we can use other response percentage such as the interval is 10% for each scenario, 10%, 15%, and 30% etc. Finally, we are able to use the conditions in Table 8.8 all together in the SPreadSHeet and determine the optimum SS.

No previous study or empirical evidence provides guidance on the recommended time interval for applying the strategy [222]. We believe that we can evaluate the network behaviour at 10-15 minutes intervals to give enough time to respond and obey the instructions. The process is then either continued or the strategy, if appropriate, is changed. In other words, after utilizing the evacuation strategy, we assess the traffic situation and assess the ability of the disaster management system on the network by comparing the performance of the proposed system to the traditional system.

In the speed strategy worksheet, the input data is different to the demand strategy worksheet as it considers another data; an example of the worksheet can be seen in Table 8.9.

Table 8.9 An example of speed strategy worksheet input data

References	Evacuation strategy start time, hh:mm	Evacuation strategy end time, hh:mm	Strategy	Controller name	Links affected	New speed m/hr	Response profile
1	08:05	09:00	Speed	Urban_9	L19:23	5	1
2	08:05	09:00	Speed	Urban_9	L79:31	10	1
3	08:05	09:00	Speed	Urban_9	L22:21	40	1
4	08:05	09:00	Speed	Urban_9	L24:25	50	1
5	08:05	09:00	Speed	Urban_9	L83:46	60	1
6	08:05	09:00	Speed	Urban_9	L89:90	70	1
7	08:30	09:30	Speed	Urban_9	L19:23	5	1
8	08:30	09:30	Speed	Urban_9	L79:31	10	1
9	08:30	09:30	Speed	Urban_9	L22:21	40	1
10	08:30	09:30	Speed	Urban_9	L24:25	50	1
11	08:30	09:30	Speed	Urban_9	L83:46	60	1
12	08:30	09:30	Speed	Urban_9	L89:90	70	1

In Table 8.9, column 2 and 3 represent the core of our contribution through applying the disaster management system in different start times and even we can control the duration of the strategy, check the effectiveness of the strategy and change it when needed.

Column 5 gives the controller name, we distribute different controllers after we diagnose the damaged link. Column 6 indicates the link name and it shows the direction as well.

In column 7, different speed limits can be propagated commensurate with the state of the streets as if there is a need to increase or decrease speed. The speed limit for this network is 30m/hr. So, in this study, we select 5 and 10 mph if we need to decrease the link speed, while we choose the speed limit between 40 and 70 mph if the speed limit is preferred to be increased. We can choose different speed limits but should be sense with the problem scale and other conditions.

Column 8 is dedicated to determine the driver response percentage. For example, no. 1 indicates that the driver response is 100% as we have another sheet inside the model, it is known as the response sheet, see Table 8.10. Again, of course we can apply any percentage we decide, we chose to apply the four percentages shown in this table.

Table 8.10 the driver response worksheet

Reference	Description	%
1	All	100
2	Percent	75
3	Percent	50
4	Percent	25

For example, no.2 in the speed strategy worksheet means reference no.2, raw 1 in Table 8.10, and it means that we expect 75% of vehicles will obey the order.

8.5.4   Speed strategy: results and evaluation

Due to a disaster impact, a considerable number of vehicles is trapped and accumulated within the network, see Figure 8.4. The figure shows the city X network while it is under the disaster impact and without any emergency system. An effective evacuation strategies policy is demonstrated to control the traffic network. Different conditions can be applied under this strategy, such as increasing and decreasing the speed limit, applied simultaneously where suitable, and applying different driver response, further details on driver response will be illustrated in Section 8.5.5. An example of the SS implementation when we use the traditional disaster system can be shown in Table 8.11.

Table 8.11 An example of a disaster impact and the speed strategy implementation for some zones, traditional disaster system

Critical zone no.	Disaster status, veh/hr	No. of accumulative vehicles, veh/hr					
		Speed limit, mph, 100%					
		40,5	50,5	60,5	40,10	50,10	60,10
1	310	308	310	307	304	314	311
2	477	461	453	475	470	469	486
3	377	371	365	386	360	363	386
4	48	48	47	49	49	50	48
5	59	59	60	57	61	62	57
6	16	13	11	14	15	14	12
7	696	681	683	679	660	672	678
8	249	240	232	242	248	263	261
9	625	627	622	626	623	624	625

Although speed strategy consists many valuable conditions that can be considered to improve the situation, the figures in Table 8.11 show that we cannot rely on this strategy if there is no monitoring the situation, which is happened if using the traditional system, so the random movement will be existed again. For example, for all speed limits, there is no difference can be spotted for the no. of accumulated vehicles in zone 4.

While, in zone 7, we notice that the no. of accumulated vehicles is slightly going down which means the vehicles is still going to their destination without any guidance all because we apply the strategy late and no cooperative is demonstrated here because of the lack of information throughout the evacuation process. To sum up, we couldn't be able to introduce an improvement in this case neither recommend a speed limit to help the vehicles in this situation.

Table 8.12 An example of a disaster impact and the speed strategy implementation for some zones, intelligent disaster system

Critical zone no.	Disaster status, veh/hr	No. of accumulative vehicles, veh/hr					
		Speed limit, mph, 100%					
		40,5	50,5	60,5	40,10	50,10	60,10
1	310	357	369	337	360	357	322
2	477	494	507	499	498	490	501
3	377	396	408	401	410	398	398
4	48	48	54	46	49	48	45
5	59	60	63	61	60	57	61
6	16	15	14	15	16	17	18
7	696	735	746	733	713	716	716
8	249	282	272	258	271	263	252
9	625	635	668	625	622	625	618

Table 8.12 demonstrates the intelligent disaster management system effectiveness. We assume that a disaster system is in place aiming to evacuate the vehicles to a pre-planned safe place. Among various speed limitations, we notice that the improvement is fluctuated between huge improvements happened to big zones and the number of vehicles in some small zones.

According to the table figures, we recommend that 50 and 5 mph, the high and low speed limitation respectively, can be recommended to achieve the positive results in the evacuation operation.

8.5.5 Driver response

A significant challenge can be raised during the evacuation operations; it is the driver's response that could change the evacuation success rate from good to bad and vice versa. Driver behaviour during evacuation strategies is very important and can be described simply as "*A successful evacuation plan reflects the high driver response percentage*". Evacuee behaviour in terms of their response to the evacuation process and dynamic changes is crucial at this level for both the planning and operational contexts. In spite of the fact that driver response is very difficult to predict in such chaos conditions, it is very important to estimate the driver response to highlight the challenges and seek to introduce reasonable measurements in developing a primary evacuation concept.

The drivers are on the streets at a time of crisis; then they either speed the evacuation process by obeying the evacuation orders and move to a specified evacuation area or they might respond negatively by returning home to collect, for example, family members. Although the drivers of emergency vehicles such as ambulance vehicles and public transportation such as buses have enough knowledge and can be considered experts of navigation [234], therefore, we do not focus on rescue team behaviour in this study.

As we attempt to form the possible best network evacuation strategies by applying the proposed intelligent management system, we need to take into consideration that the individual decision-making and driver response considerably affects the network evacuation.

Responses to emergency situation and behaviour in travel choices may be considered difficult and complicated to precisely quantify in the evacuation strategies [188]. However, driver response to evacuation pre-plan was part of our model design.

It is important to note that the transportation routes are not strictly enforced; this means that evacuees can select and alter their route according to their knowledge. Also, we can say that the evacuees could have trouble choosing the road as their route selection might be made based upon an imperfect knowledge of evacuation information. Drivers encountering congestion on their preferred route will only divert if the alternative route is uncongested. They cannot look ahead to make an "optimal" routing selection. Meanwhile, public services such as buses are relatively flexible and responsive to local needs as planned as the bus drivers and passengers are likely to provide an immediate cooperative response to the evacuation management system. As discussed earlier in Section 8.5.3, we have employed different driver response, see Table 8.10, to illustrate the importance of this factor on the whole operation.

The computation results shown in Table 8.12 show the vital role of some fundamental keys for the SS during and after the disaster. We highlight the number of accumulated vehicles in critical zones in order to investigate the strategy impact. Also, a sample of the simulation results can be seen which presents two different conditions: 100% and 50% driver response in the case of applying different speed limits for different network links, low speed 5 & 10 mph and high speed of 40, 50 & 60 mph.

Table 8.12 shows the improvement which can be achieved from applying the highest driver response, 100%, with the speed limit, 5 and 50 mph, together with our intelligent disaster management system. 100% driver responses follow the strategy order would lead to increasing the number of accumulated vehicles in critical zones compared to the other speed limitation with the same percentage. Also, significant strategy performance outcomes can be seen when we compare the results to the disaster scenario (no. of accumulated vehicles). In contrast, when we apply 50% driver response, half of the zones still show an improvement in compliance although the rest show a reduction in numbers which means they might affect the evacuation strategy operations for the entire network.

Example of results in Table 8.12, which show the speed strategy positive impact through using different conditions, is plotted in Figure 8.7.
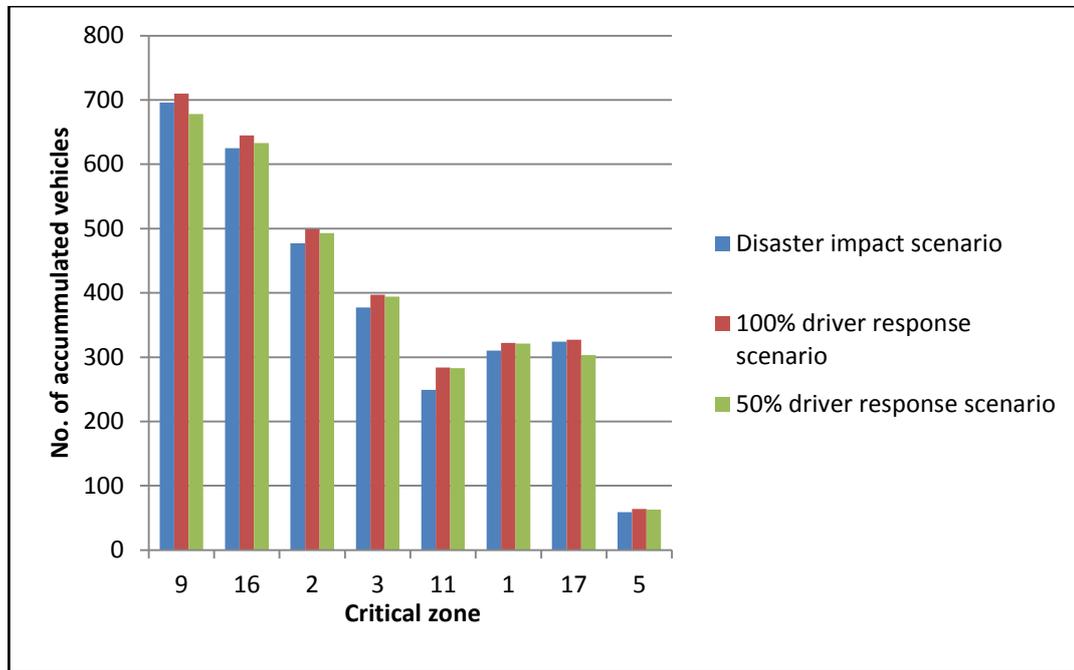

Figure 8.7 An example of results which show the speed strategy impact within different conditions

In terms of the traffic flow improvements and balance in resources usage, the computation results produce good results when we use our intelligent disaster system compared to a traditional disaster management system, see Figure 8.8 and Figure 8.9.

The speed strategy figures depict the difference between the traditional and intelligent disaster systems. In the proposed system, the black lines, blocked streets with 0 volumes, can exist in few lines around the disaster area. While when using the traditional systems, it seems we have not achieved such good results as in the new system. Also, green links can be seen in new system figure while no green links can be seen in old system as it is hardly to develop the fast communication neither in real – time. Finally, in Figure 8.9 we apply 100% driver response, and as explained above, it can be any present.

Also, we demonstrate different driver response percentages while we implement the speed strategy. Note Figure 8.9, shows the traffic network response while 100% of drivers have responded to the strategy orders. To facilitate the implementation of the strategy, we expect all links which are categorized to participate in the strategy; we attempt to ignore all obstructions which could delay the strategy process, for instance the signal control so no acceleration/deceleration and delay can exist. If possible, we try to guide the drivers through links that are not controlled by a roundabout so we can avoid the delay caused by the traffic overlap. For further details, we introduce the traffic network of the city X under different driver response percentages, see Appendix B.
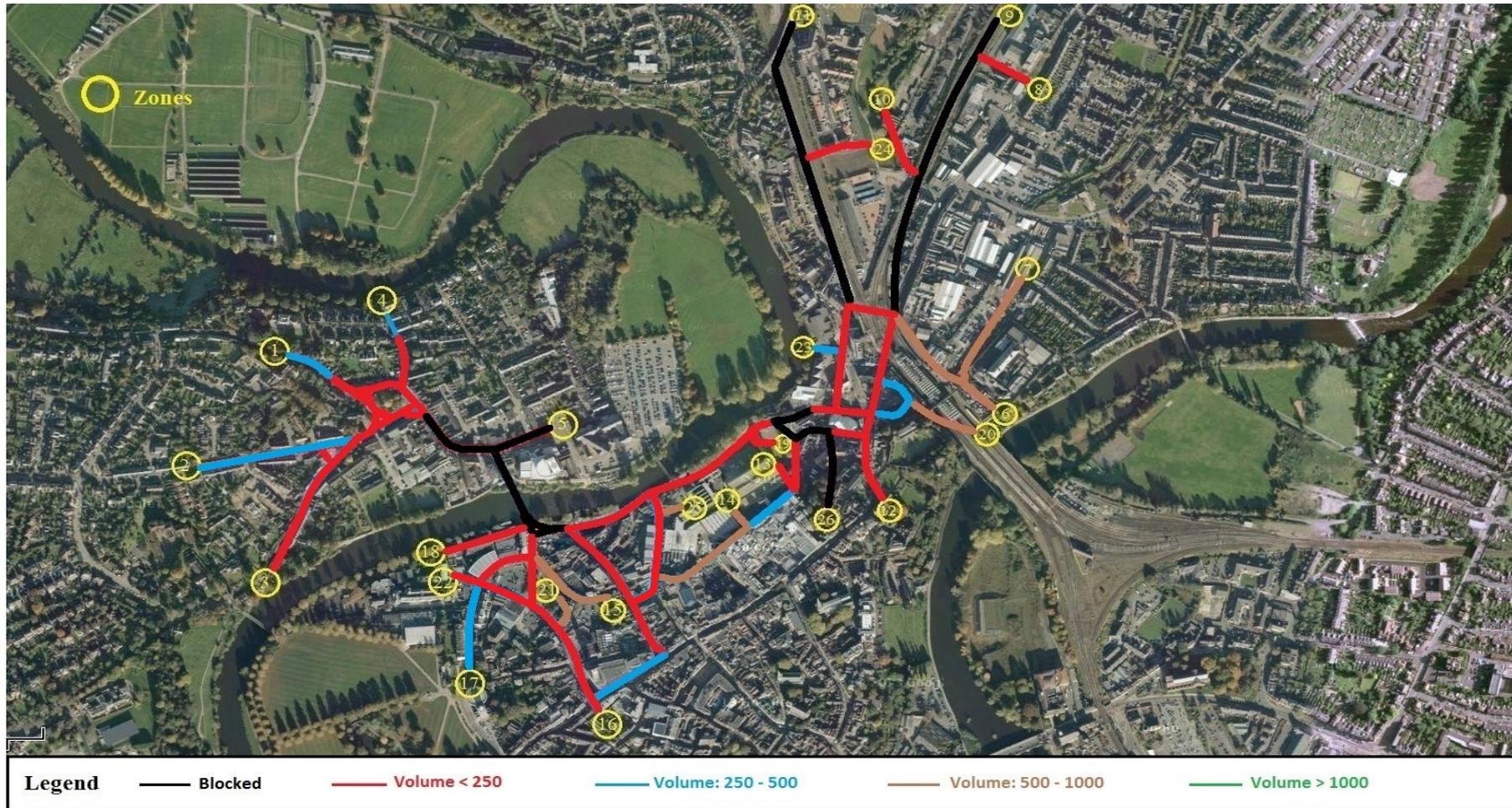
Figure 8.8 The transportation network of the city X while using the speed strategy, traditional management system
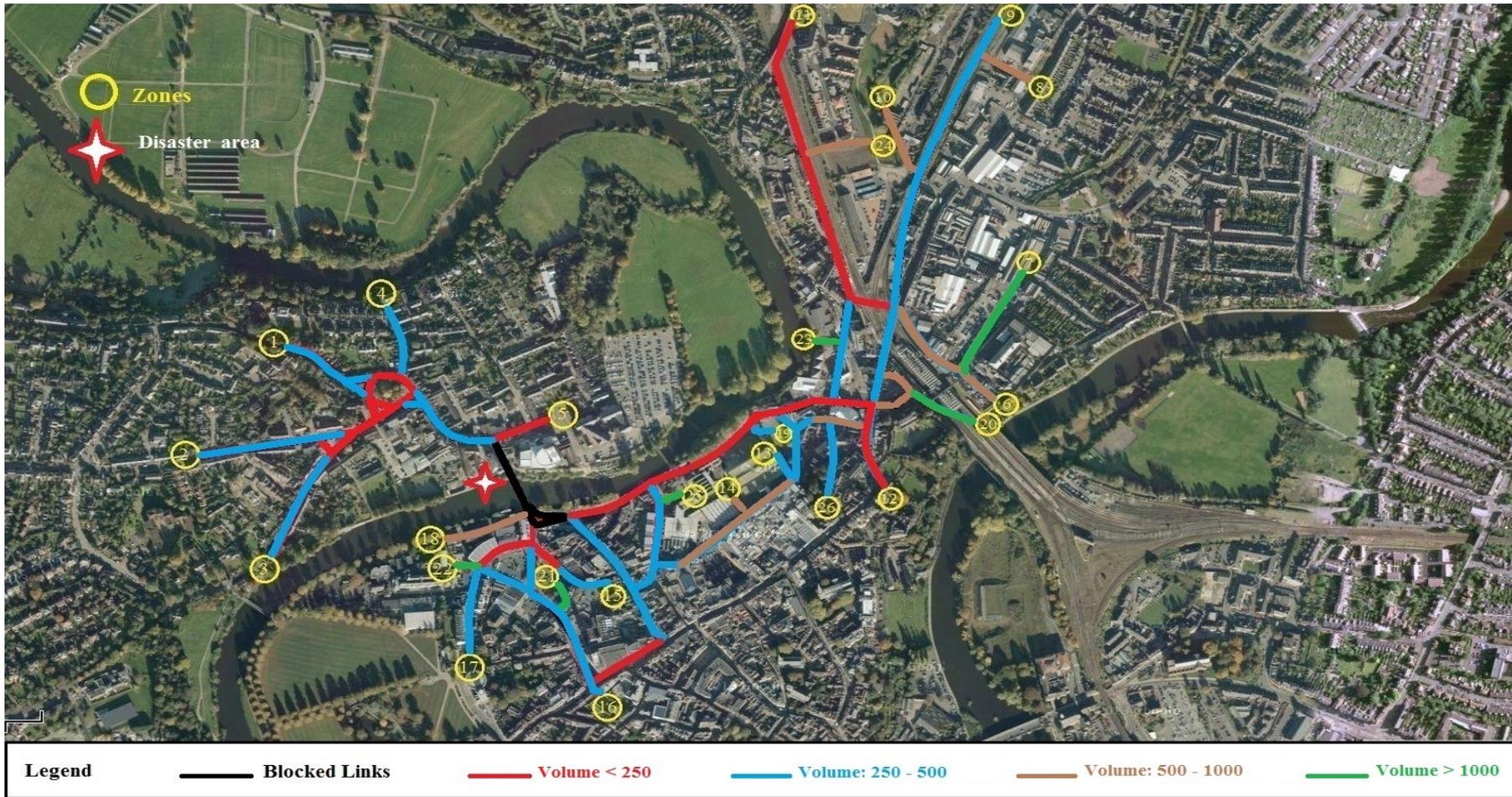
Figure 8.9 The transportation network of the city X while using the speed strategy, our proposed disaster management system

8.5.6   Demand and speed strategies, simultaneously

Two different evacuation strategies are applied simultaneously; Speed and Demand strategies are selected to present the effectiveness of the smart proposed system in this section.

In a normal situation, most city links speed is limited to 30mph. However, after the disaster hits the city and vehicles start to move under shock anarchy results. So, applying the smart disaster management system is recommended, providing real-time network information, including different evacuation strategies. Exploiting the traditional management system means sending late warnings, because of some tools limitations we will not be able to change/update the strategies, conditions, depending on the real network situation. In the case of using the SS, a wide range of conditions is applied. For example, we are able to increase the speed limit for some critical links as we aim to facilitate the escape from the dangerous area as quickly as possible, and/or slow the speed for other links to prevent vehicles moving towards the disaster area and other affected links, while the smart disaster management system gives the opportunity to send and receive the information earlier than the traditional management systems. Consequently, we could manipulate the scenario conditions depending on the real-time data received from various communication technologies including VANETs. In the latter scenario, the different speed conditions can be applied together as required by the situation.

The Demand Strategy has different input data to the SS, as discussed earlier in Section 8.5.1, and can still be implemented simultaneously. It means, same worksheet can be ordered and holds two different evacuation strategies. There can be more than two strategies, see Figure 8.10.

Figure 8.10 An example of worksheet for more than one strategy

Figure 8.10 introduced the worksheet while we use different strategies. Despite of it is the same way when we create a worksheet for each strategy, we put them in one sheet to ensure that both strategies are working together no matter which one is the first, for them job no matter which raw are they but the important is the start and end strategy time, here in column 2 and 3.

8.5.7   Results and discussion

Due to a disaster impact, a considerable number of vehicles is trapped and accumulated inside the network. An effective evacuation strategies policy is demonstrated to control the traffic network.

A traditional disaster management systems dispatch the disaster information slightly late. The driver behaves randomly, they might select the least congested routes, or follow others as they prefer to stick with the majority or follow the routes that they feel familiar with them, or select the routes that have been selected by the decision makers. Random selection above would likely consume time and increase the opportunity of having a chaos network and hence makes the emergency strategies more difficult to implement. Literally, 30 minutes after the disaster hits the city is enough to prevent employing the strategies. For example, the vehicles keep going out of the zones without any idea what is going around them and increase the congestion and it becomes very difficult to drive the vehicles out of the danger area and possibly preventing the implementing of other strategies.

By contrast, using our proposed smart disaster system and propagating the speed and demand strategies as quickly as possible will lead to a considerable improvement in the traffic network performance, see Figure 8.12. The system propagates the effective and practical strategies and makes a huge difference in the traffic performance. Here, we are able to exploit the strategies, isolated and together, as we have time to prevent the vehicles going towards the city and monitor the vehicles that are already driving inside the network. In other words, we stop drivers entering the city network through utilizing the demand strategy and at the same time controlling the traffic movement by implementing the speed strategy, by imposing different limitation according to the need, and slow/speed the movement towards the different areas.

Also, here we emphasise a very important issue, that we can implement successfully both strategies together as stopping the drivers from entering the network would help to decrease the number of vehicles already inside the network and facilitate the speed strategy implementation, see Figure 8.12.
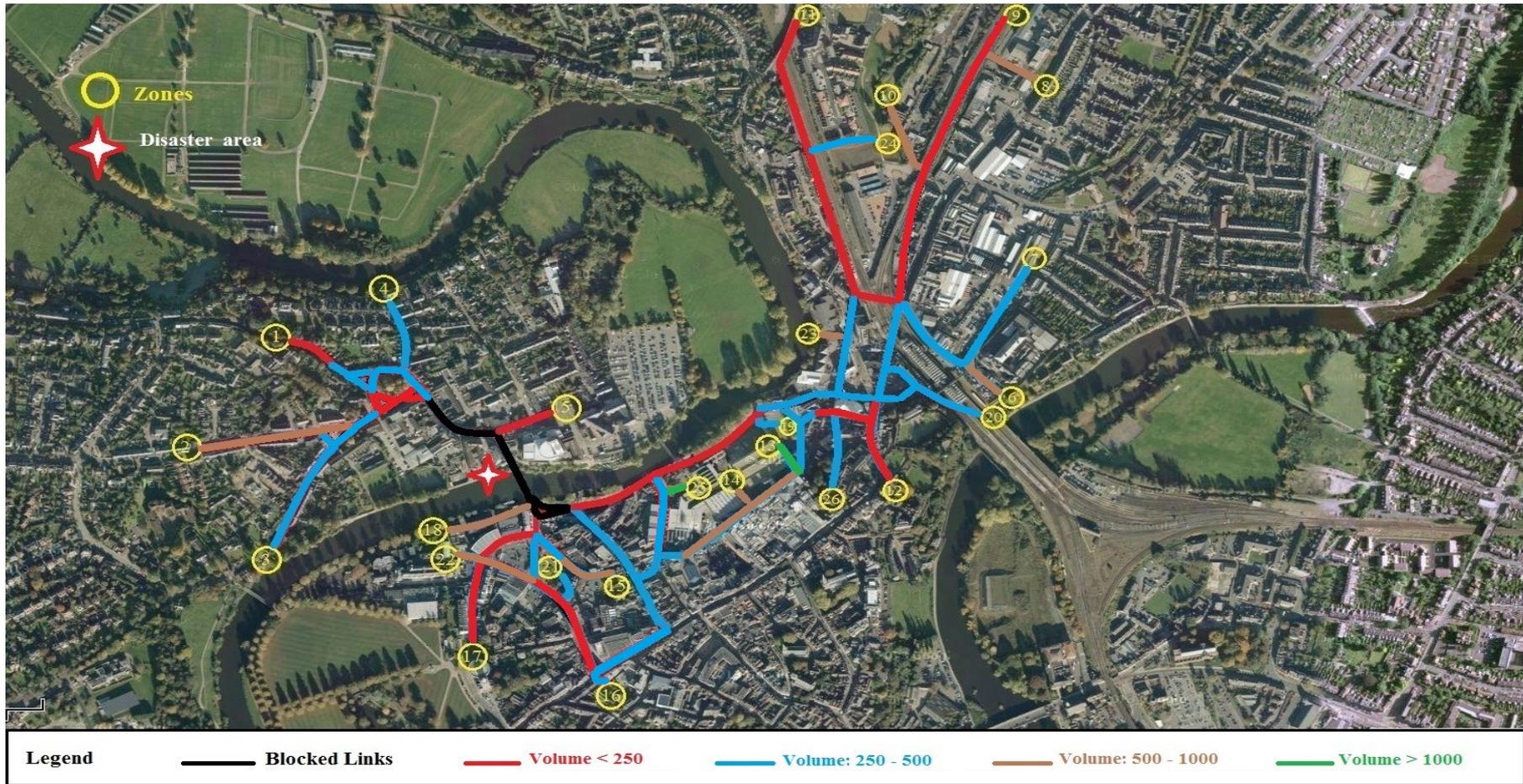
Figure 8.11 The transportation network of the city X while using demand and speed strategies, a traditional disaster management system
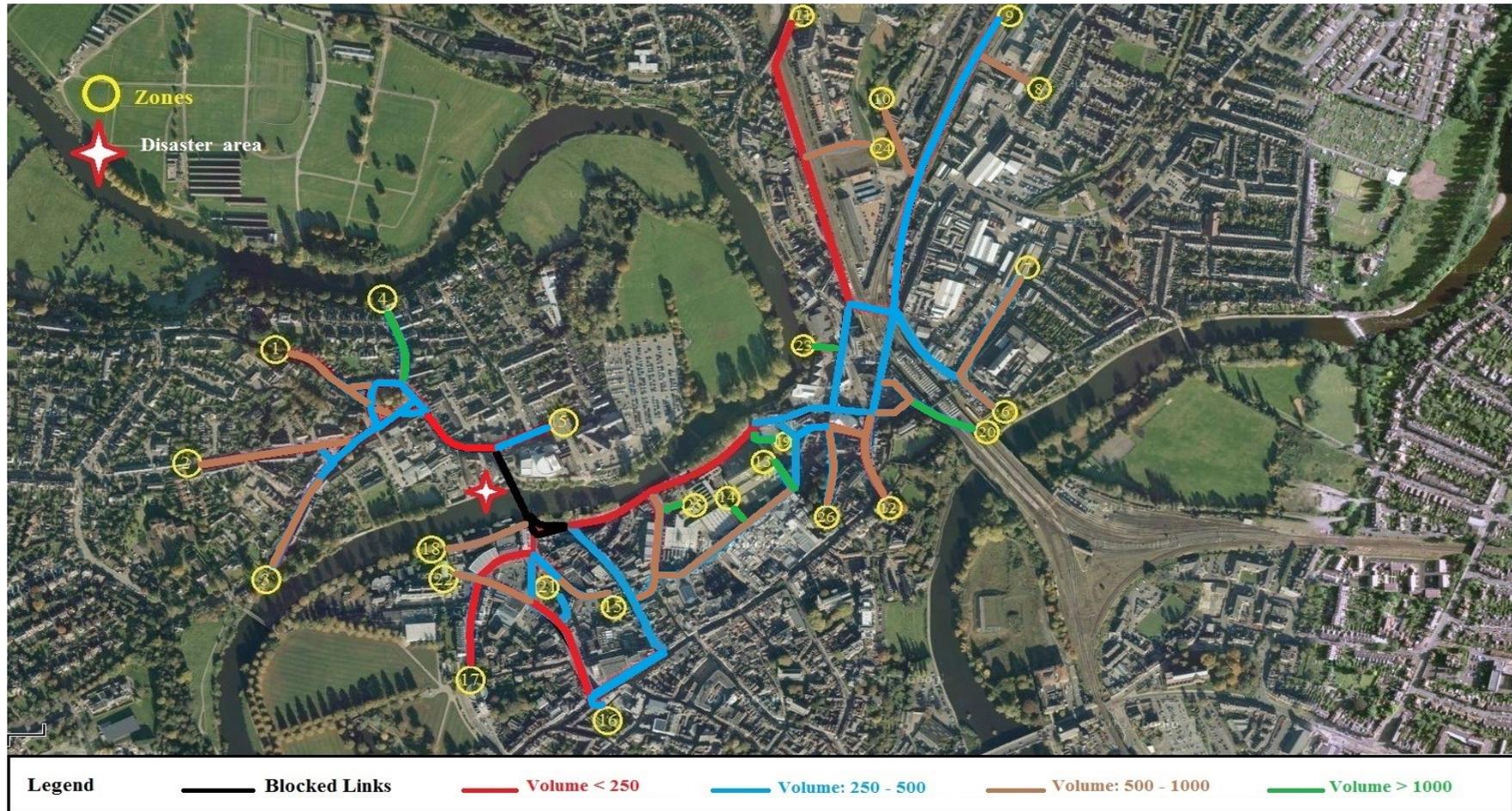
Figure 8.12 The transportation network of the city X while using demand and speed strategies, our intelligent disaster management system

More green links can be seen in Figure 8.12, this is because the disaster management centre now is able to propagate adequate and effective strategies while monitoring the traffic movement in real-time. Also, more blue links, with a volume between 250 -500 vehicle per hour, can be recognized.

In addition, there is an improvement in flow rate of critical links. Many blocked links which have zero volume, depicted by the roads coloured in black, are turned into red and some blues which means an improvement seemed to occur to the whole network. Also, we note that the few links which are coloured in brown, representing the volume between 500 -1000 vehicle per hour, become green which means that the volume of these links has been increased because our objective is to balance using the network links as much as possible. Finally, we should mention here that the human lives' saving is mainly achieved by using the demand strategy.

8.6   S-Paramics ITS System limitations

Many advantages are obtained from using S-paramics ITS System, however, some very important drawbacks have been spotted, and they are:

1. Two types of controllers can be set into the model, the area controllers pass (or would pass if they worked) messages to all the vehicles on the set of links it is attached to in the model. The link controller passes messages to one link only and only to vehicles that pass the position of the controller. So, the controllers are either position based (link option) or area based (set of links). The link option is really for message signs by the side of the road while the area option is for broadcast messages. S-Paramics ITS system manual reported that the controllers were able to pass the messages to an area where a controller dominates on several links on both directions. Whilst, when we apply this feature we found that it does not mean that we can use the area based ITS controller scope. The only way to do this is to add an ITS controller on each of the links we are interested in and configure them all to provide the same message in our SPreadSHeet. It does mean we have to have a lot of them and there will be a variation in the time each vehicle receives the message - when it drives past the controller.

2. The location selection of the controllers within the network is very important. We avoid controllers on very short links, leaving adequate distance: If the drivers get the evacuation and diversion messages a second or so later at the start of the next link then the likely effect will be too great. Also we avoid positioning controllers close to the end (and probably close the beginning too) and we make sure that they are at least a timestep away from the stopline locus points. The wrong choice of the controller position leads a failure to send the message and makes the SNMP interface diagnoses a problem and this can be seen by a bug message at "the controller is not inside the link range" [181].

3. When we apply the speed to zero, we cannot run the simulation model. This is very important reason so we selected to develop our SNMP controller so we can make any changes within a time to show the proposal components.

CONCLUSIONS AND FUTURE WORK

Information and Communication Technologies (ICT) are continuing to make a profound impact on the way we live and work, enabling our move towards a Digital Economy. Transportation is an important dimension of this move towards a digital economy. The importance of disaster management systems has grown tremendously in recent times due to the many manmade and natural disasters in recent years such as September 2001, July 2005 London bombings and the 2011 Japan earthquake and tsunami disaster. Next generation economies will rely on Intelligent Transportation Systems (ITS), enabled through increased ICT penetration, aiming to increase safety and system efficiency, reduce accidents, congestion and journey times, improve its carbon footprint and manage emergencies and disasters.

Disasters, manmade and natural, are a cause of great economic and irrecoverable human losses each year throughout the world. Conventional methods of disaster management system have shown little prospects of realizing the true potential of current and emerging technologies.

Smart cities rely on a converged, ubiquitous infrastructure to provide a high quality of life to their people through efficient use of resources. We have witnessed unprecedented advancements in ICT over the last few decades and the role of ICT technologies in Intelligent Transportation Systems is growing at a tremendous rate. VANETs, sensor networks, social networks, C2X technologies are enabling transformational capabilities for transportation. Our ability to monitor and manage transportation systems in real-time and at high granularities has grown tremendously due to sensor and vehicular networks that generate a huge amount of extremely useful data. However, a major challenge in realizing the potential of ITS is the interworking and integration of multiple systems and data to develop and communicate a coherent holistic picture of transportation, environment and other systems.

This is particularly difficult given the lack of data and systems interoperability as well as the business models to develop such an advanced infrastructure which requires coordination between many stakeholders and the general public. Cloud Computing has emerged as a technology, coupled with its innovative business models, which has the potential to revolutionize the ICT, ITS and smart cities landscape.

This PhD research aims to propose and evaluate a disaster management system based on the emerging ICT technologies with a focus on transportation in urban environments. To this end, we presented, in this thesis, our work on an intelligent disaster management system based on Vehicular Ad hoc Networks (VANETs) and Cloud Computing. We demonstrated the effectiveness of our system through modelling the impact of disaster on different real city transport environments and compared it with the case where our system was in place.

In this thesis, the disaster management has contributed towards the architecture, models, technologies and software for the implementation and evaluation of the disaster management system. The particular contribution of this study is in the modelling and simulation of road traffic for disaster and evacuation scenarios. The purpose is the assessment of mass evacuation plans at different disaster scales and for the diversity of density area (population), as well as the identification and prioritization of deficiencies on those systems that could impede disaster management including evacuation strategies implementation.

In this study, a detailed introduction to the background and literature review on Intelligent Transportation Systems (ITS) and disaster management has been provided. Also a fairly detailed introduction to the modelling and simulation methods that we have used to model disaster and evacuation scenarios and analyses of our proposed system has been presented. These included a range of techniques to model evacuation scenarios including OmniTRANS and S-Paramics software. A broad introduction to the area of traffic modelling covering various classes of modelling and simulation methodologies was provided. Disaster scenarios of varying scales involving 3 different cities of various sizes and characteristics are modelled and analysed. These analyses carried out over a range of cities and scenarios fed into establishing a suitable software model which is capable of introducing innovations in the disaster management area as well as in the broader transportation area.

In our earlier work, we leveraged the advancements in the ICT technologies - including ITS, VANETs, social networks, mobile and Cloud computing technologies - to propose an intelligent disaster management system for future (or smart) city environments. By exploiting these latest technologies the system is able to gather information from multiple sources and locations (using VAENTS, Smartphone and other technologies), including from the point of incident, and is able to make effective strategies and decisions (using e.g. high performance computing (HPC)), and propagate the information to vehicles and other nodes in real-time. The proposed system details in Section 5.1 [15] and extended in Section 5.3 [224], in that the system model was improved by means of introducing a novel message propagation algorithm through VANETs, and the effectiveness of the system was validated by means of extended simulation results.

These earlier works were based on macroscopic traffic modelling. Then, we focused on microscopic models for the design and evaluation of our system with the aim to gain additional insight into the problem domain, to validate the earlier system analysis, and to improve system functionality and performance.

We investigate the AVO impact on the evacuation process time and present little calculation in Section 6.4. The results have shown that AVO contributes effectively in evacuation plans that are in place; this has indicated that neighbourhood may not be able to evacuate in a timely manner without considering higher values to this factor. Ideally, the higher occupancy factor assumed the lowest evacuation time achieved, nevertheless it's believed that in such situation is very difficult to predicate the precise factor as we have various driver responses to such appeal.

We developed a model to investigate the disaster management system performance on the evacuation operation by employing different city evacuation strategies. We reported our recent work on two major evacuation strategies, Demand Strategies (DS) and Speed Strategies (SS) which provide significantly improved evacuation results in smart cities settings. The results show significant improvements in terms of the number of vehicles used. Please see [235], [236] and [237].

We achieved substantial benefits in terms of improved and balanced traffic flow, the number of people evacuated from the city, a balanced use of transportation resources and smooth evacuation.

9.1 Future work

Future improvements for the proposed work are suggested in this section:

- The current thesis has demonstrated three urban cities to examine the proposed work. We are planning to get more cities to test our system with their condition in future works.

- Also, we are planning to extend our work to be available for the rural city environment (but we should focus on one important issue: the system could be implemented as we depend on providing advanced technologies).

- Furthermore, the future work will focus on further analysis and validation of additional disaster evacuation strategies to determine the effective strategy/s, and weather isolated or simultaneously.

- Additionally, we are able to validate the driver response results; which have been discussed in Chapter 8, as we could carry out a survey to obtain solid results on the exact behaviour of the driver.

- Finally, the system could be enhanced further by considering converting it into Heuristic one by training the system to recognise and process the different parameters to it, e.g. disaster scale, city characteristics, population, disaster area etc., and therefore dynamically and automatically choosing the appropriate strategy to fit the scenario in hand.

REFERENCES

[1]   J. Hunt and D. Willetts, "Digital Infrastructure." Council for Science and Technology, 2010.

[2]   P. Goodwin, "The Economic Costs of Road Traffic Congestion," UCL (University College London), UK, 2004.

[3]   S. Gooding, "Congestion Management - What are the Issues," presented at the Proceedings of the 5th Conference Reforming Highways Maintenance : Making Change Happen, UK, 2012.

[4]   Transport Committee, "Road Pricing: The Next Steps," House of Commons, UK, 7, 2005.

[5]   K. M. Rahman, T. Alam, and M. Chowdhury, "Location based early disaster warning and evacuation system on mobile phones using OpenStreetMap," in *Proceedings of the Conference on Open Systems (ICOS)*, 2012, pp. 1–6.

[6]   FHWA, "Emergency Transportation Operations." [Online]. Available: http://ops.fhwa.dot.gov/eto_tim_pse/index.htm. [Accessed: 27-Jun-2011].

[7]   Caribbean Disaster Emergency Response Agency, "ICT in Disaster Management_ Enhancing the Effectiveness of Information and Communication Technology Applications for Disaster Management in the Caribbean Region," 2006.

[8]   N. Nouali, N. Bouchama, A. Bendjoudi, A. Babakhouya, S. Yahiaoui, Y. Belhoul, H. Zeghilet, and N. Guellati, "Using Information Technology for Enhancing Disaster Management." [Online]. Available: http://www.scribd.com/doc/16654082/Using-Information-Technology-for-Enhancing-Disaster-Management. [Accessed: 16-Jun-2011].

[9]   R. Wallace, "Japan Warns of Many Deaths from Devastating Quake," Mar-2011.

[10]   U.S. Department of Transportation and U.S. Department of Homeland Security, "Catastrophic Hurricane Evacuation Plan Evaluation," USA, Report to Congress, 2006.

[11]   M. Reilly, "Japan's Quake Updated to Magnitude 9.0," *New Sci.*, 2011.

[12]   Transport Canada, "Commissioner of the Environment and Sustainable Development," Office of the Auditor General of Canada, Canada, 2011.

[13]   Luis R. Izquierdo, Segismundo S. Izquierdo, José Manuel Galán, and José Ignacio Santos, "Techniques to Understand Computer Simulations: Markov Chain Analysis," *J. Artif. Soc. Soc. Simul.*, vol. 12, 2009.

REFERENCES

[14]   Z. Alazawi, "Emergency Response in Transportation Systems (ERTS)," School of Engineering, Swansea University., Swansea, UK, Technical Report, 2011.

[15]   Z. Alazawi, S. Altowaijri, R. Mehmood, and M. B. Abdljabar, "Intelligent Disaster Management System Based on Cloud-Enabled Vehicular Networks," in *11th International Conference on ITS Telecommunications (ITST)*, Russia, 2011, pp. 361–368.

[16]   J. S. Sussman, *An Introduction to Intelligent Transportation Systems*. Springer, 2005.

[17]   "Intelligent   Transportation   System   -,"   2011.   [Online].   Available: http://en.wikipedia.org/wiki/Advanced_Transportation_Technologies.   [Accessed: 14-Feb-2011].

[18]   Ministry of Transportation Government of Ontario, "Intelligent Transportation Systems   (ITS),"   2011.   [Online].   Available: http://www.mto.gov.on.ca/english/engineering/its/. [Accessed: 17-Apr-2011].

[19]   West Sussex County Council, "Intelligent Transport Systems," Dec-2010. [Online]. Available: http://www.westsussex.gov.uk/leisure/getting_around_west_sussex/roads_and_pathways/traffic/managing_congestion-1/intelligent_transport_systems.aspx. [Accessed: 15-Feb-2011].

[20]   "Truck and Bus Driver/Commercial Vehicle Operation," 2011. [Online]. Available: http://www.educationdepartment.org/degree/49-0205. [Accessed: 05-May-2011].

[21]   "Center   for   Intelligent   Systems   Research,"   2011.   [Online].   Available: http://www.cisr.gwu.edu/research/control_details.html. [Accessed: 05-May-2011].

[22]   "Public   Transport,"   2011.   [Online].   Available: http://en.wikipedia.org/wiki/Public_transport. [Accessed: 21-Feb-2011].

[23]   "Digital   Economy,"   *Wikipedia*,   2011.   [Online].   Available: http://en.wikipedia.org/wiki/Digital_economy. [Accessed: 14-Feb-2011].

[24]   Department of Broadband, Communication and the Digital Economy, "Australia's Digital Economy," *Australia's Digital Economy | Department of Broadband, Communications and the Digital Economy*, 2011. [Online]. Available: http://www.dbcde.gov.au/digital_economy/future_directions_of_the_digital_economy/australias_digital_economy_future_directions/final_report/australias_digital_economy#digitaleconomy. [Accessed: 24-Apr-2011].

[25]   A. Torok, P. Laborczi, and G. Gerhath, "Spatially Constrained Dissemination of Traffic Information in Vehicular Ad Hoc Networks," in *Proceedings of the 68th Conference on Vehicular Technology Conference (VTC)*, 2008, pp. 1 –5.

[26]   D. Sormani, G. Turconi, P. Costa, D. Frey, M. Migliavacca, and L. Mottola, "Towards Lightweight Information Dissemination in Inter-Vehicular Networks," in *Proceedings of the 3rd International Workshop on Vehicular Ad Hoc Networks*, USA, 2006, pp. 20–29.

REFERENCES

[27]   M. Uttamchand, "Vehicle-2-Vehicle Communication: A Technology Case Study," Master thesis, State University of New York, Institute of Technology, USA, 2009.

[28]   Q. Xu, "Control, Estimation, and Communication Design Applied to Active Vehicle Safety Systems," PhD Thesis, University of California, Berkeley, USA, 2005.

[29]   "A1 Brief introduction to Intelligent Transportation System, ITS.pdf." .

[30]   "Innovative Mobility Research - Intelligent Transportation Systems (ITS)," 03-Mar-2011. [Online]. Available: http://www.innovativemobility.org/its/index.shtml. [Accessed: 03-Mar-2011].

[31]   "ITIF: Explaining International IT Application Leadership: Intelligent Transportation Systems," 2011. [Online]. Available: http://archive.itif.org/index.php?id=332. [Accessed: 04-May-2011].

[32]   K. C. Mouskos, J. Greenfeld, and L. J. Pignataro, "Toward a Multi-Modal: Advanced Traveler Information System," *Spring*, vol. 4, 1996.

[33]   "Zaon XRX Collision Avoidance System," 01-May-2011. [Online]. Available: http://gps.co.uk/Collision-Avoidance/-Zaon-XRX-Collision-Avoidance-System/p-88-403/. [Accessed: 01-May-2011].

[34]   Program Office (ITS JPO) of the U.S. Department of Transportation (U.S. DOT), "Intelligent Transportation Systems (ITS)," *Research and Innovative Technology Administration, RITA*, 2009. [Online]. Available: http://www.its.dot.gov/index.htm. [Accessed: 24-Feb-2011].

[35]   A. M. Khan, "Intelligent Infrastructure-Based Queue-End Warning System for Avoiding Rear Impacts," *IET Intell. Transp. Syst.*, vol. 1, no. 2, pp. 138–143, 2007.

[36]   Government of Canada; Transport Canada; Programs, "Intelligent Transportation Systems in 98 B-Line Rapid Bus Service: Advanced Technology at Work," 2011. [Online]. Available: http://www.tc.gc.ca/eng/programs/environment-utsp-intelligenttransportationsystems-945.htm. [Accessed: 01-May-2011].

[37]   "SDOT - Intelligent Transportation Systems (ITS)," 04-May-2011. [Online]. Available: http://www.seattle.gov/transportation/its.htm. [Accessed: 04-May-2011].

[38]   H.-T. Lim, K. Weckemann, and D. Herrscher, "Performance Study of an In-Car Switched Ethernet Network without Prioritization," in *Proceedings of the Third International Conference on Communication Technologies for Vehicles*, Berlin, Heidelberg, 2011, pp. 165–175.

[39]   "ETSI Intelligent Transport Systems," 01-May-2011. [Online]. Available: http://www.etsi.org/website/Technologies/IntelligentTransportSystems.aspx. [Accessed: 01-May-2011].

[40]   "Advanced Driver Assistance (ADAS)," *Analog Devices*, 2011. [Online]. Available:

http://automotive.analog.com/en/advanced-driver-assistance/segment/am.html. [Accessed: 07-May-2011].

[41]   "ITS for sustainable communities and success stories.pdf." .

[42]   M. S. Idrees, H. Schweppe, Y. Roudier, M. Wolf, D. Scheuermann, and O. Henniger, "Secure Automotive On-Board Protocols: A Case of Over-the-Air Firmware Updates," in *Communication Technologies for Vehicles*, vol. 6596, Berlin, Heidelberg: Springer Berlin Heidelberg, 2011, pp. 224–238.

[43]   T. Mangel, M. Michl, O. Klemp, and H. Hartenstein, "Real-World Measurements of Non-Line-Of-Sight Reception Quality for 5.9GHz IEEE 802.11p at Intersections," in *Communication Technologies for Vehicles*, vol. 6596, Berlin, Heidelberg: Springer Berlin Heidelberg, 2011, pp. 189–202.

[44]   B. Villeforceix, "Delivering Broadband Internet Access for High Speed Trains Passengers Using an Innovative Network Mobility Solution," in *Communication Technologies for Vehicles*, vol. 6596, T. Strang, A. Festag, A. Vinel, R. Mehmood, C. Rico Garcia, and M. Röckl, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, 2011, pp. 34–44.

[45]   Z. Nabi, A. Alvi, and R. Mehmood, "Towards Standardization of In-Car Sensors," in *Communication Technologies for Vehicles*, vol. 6596, Berlin, Heidelberg: Springer Berlin Heidelberg, 2011, pp. 216–223.

[46]   H. Noureddine, D. Castelain, and R. Pyndiah, "Train Tracking and Shadowing Estimation Based on Received Signal Strength," in *Communication Technologies for Vehicles*, vol. 6596, Berlin, Heidelberg: Springer Berlin Heidelberg, 2011, pp. 23–33.

[47]   F. Ponte Müller, J. M. Reveriego Sierra, B. Kloiber, M. Röckl, and T. Strang, "Interoperability Testing Suite for C2X Communication Components," in *Communication Technologies for Vehicles*, vol. 6596, Berlin, Heidelberg: Springer Berlin Heidelberg, 2011, pp. 203–215.

[48]   M. Aguado, J. Astorga, J. Matias, and M. Huarte, "The MIH (Media Independent Handover) Contribution to Mobility Management in a Heterogeneous Railway Communication Context: A IEEE802.11/802.16 Case Study," in *Communication Technologies for Vehicles*, vol. 6596, Berlin, Heidelberg: Springer Berlin Heidelberg, 2011, pp. 69–82.

[49]   "Vehicle Tracking \ GPS Tracking \," 2011. [Online]. Available: http://www.uktelematicsonline.co.uk/. [Accessed: 24-Mar-2011].

[50]   B. Schweiger, P. Ehnert, and J. Schlichter, "Simulative Evaluation of the Potential of Car2X-Communication in Terms of Efficiency," in *Communication Technologies for Vehicles*, vol. 6596, T. Strang, A. Festag, A. Vinel, R. Mehmood, C. Rico Garcia, and M. Röckl, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, 2011, pp. 155–164.

[51]   P. Gomes, C. Olaverri-Monreal, M. Ferreira, and L. Damas, "Driver-Centric VANET Simulation," in *Communication Technologies for Vehicles*, vol. 6596, Berlin, Heidelberg:

Springer Berlin Heidelberg, 2011, pp. 143–154.

[52]   S. A. Mohammad, A. Rasheed, and A. Qayyum, "VANET Architectures and Protocol Stacks: A Survey," in *Communication Technologies for Vehicles*, vol. 6596, Berlin, Heidelberg: Springer Berlin Heidelberg, 2011, pp. 95–105.

[53]   M. Smith, "Intelligent Control of Urban Road Networks: Algorithms, Systems and Communications," in *Communications Infrastructure. Systems and Applications in Europe*, vol. 16, R. Mehmood, E. Cerqueira, R. Piesiewicz, and I. Chlamtac, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, 2009, pp. 116–127.

[54]   R. K. Schmidt, B. Kloiber, F. Schüttler, and T. Strang, "Degradation of Communication Range in VANETs Caused by Interference 2.0 - Real-World Experiment," in *Communication Technologies for Vehicles*, vol. 6596, Berlin, Heidelberg: Springer Berlin Heidelberg, 2011, pp. 176–188.

[55]   M. Elkotob and E. Osipov, "iRide: A Cooperative Sensor and IP Multimedia Subsystem Based Architecture and Application for ITS Road Safety," in *Communications Infrastructure. Systems and Applications in Europe*, vol. 16, Berlin, Heidelberg: Springer Berlin Heidelberg, 2009, pp. 153–162.

[56]   "ITS Technologies - Devices," 2011. [Online]. Available: http://www.walkinginfo.org/pedsmart/tlite.htm. [Accessed: 03-May-2011].

[57]   A. Lehner, C. Rico García, T. Strang, and O. Heirich, "Measurement and Analysis of the Direct Train to Train Propagation Channel in the 70 cm UHF-Band," in *Communication Technologies for Vehicles*, vol. 6596, Berlin, Heidelberg: Springer Berlin Heidelberg, 2011, pp. 45–57.

[58]   D. Lill, M. Schappacher, S. Islam, and A. Sikora, "Wireless Protocol Design for a Cooperative Pedestrian Protection System," in *Communication Technologies for Vehicles*, vol. 6596, Berlin, Heidelberg: Springer Berlin Heidelberg, 2011, pp. 119–130.

[59]   R. Sharma and P. Kanungo, "An Intelligent Cloud Computing Architecture Supporting e-Governance," in *Proceedings of the 17th International Conference on Automation and Computing (ICAC)*, 2011, pp. 1–5.

[60]   B. J. S. Chee and J. Curtis Franklin, *Cloud Computing: Technologies and Strategies of the Ubiquitous Data Center*. CRC Press, Inc., 2010.

[61]   P. Murray, "Enterprise Grade Cloud Computing," Nuremberg, Germany, 2009, pp. 1–10

[62]   M. Böhm, S. Leimeister, C. Riedl, and H. Krcmar, "Cloud Computing – Outsourcing 2.0 or a new Business Model for IT Provisioning?," in *Application Management*, Wiesbaden: Gabler, 2011, pp. 31–56.

[63]   L. Youseff, M. Butrico, and D. Da Silva, "Toward a Unified Ontology of Cloud Computing," presented at the Grid Computing Environments Workshop. GCE, 2008, pp. 1–

REFERENCES

10.

[64]   J. Zibulewsky, "Defining disaster: the emergency department perspective," *Proc. Bayl. Univ. Med. Cent.*, vol. 14, no. 2, pp. 144–149, 2001.

[65]   "The Definition of Disaster," *Dictionary.com*. [Online]. Available: http://dictionary.reference.com/browse/disaster. [Accessed: 21-Nov-2012].

[66]   University of Wisconsin Disaster Management Centre, "An Overview of Disaster Management." UNDRO, 1992.

[67]   A. Minhans, "Formulation of Traffic Management Strategies in Cases of Disasters," Social Science Research Network, Rochester, NY, SSRN Scholarly Paper ID 1636196, 2010.

[68]   B. Mei, "Development of Trip Generation Models of Hurricane Evacuation," Master thesis, China, 2002.

[69]   N. T. Yap, "Disaster Management, Developing Country Communities & Climate Change: The Role of ICTs." 2011.

[70]   R. W. Perry, "Incident Management Systems in Disaster Management," *Disaster Prev. Manag.*, vol. 12, no. 5, pp. 405–412, 2003.

[71]   F. Souza and I. Kushchu, "Mobile Disaster Management System Applications - Current Overview and Future Potential -."

[72]   T. Litman, "Lessons From Katrina and Rita: What Major Disasters Can Teach Transportation Planners," *Transp. Eng.*, vol. 132, pp. 11–1, 2006.

[73]   D. Coyle and M. B. Childs, "The Role of Mobiles in Disasters and Emergencies," 2005.

[74]   D. Guha-Sapir, F. Vos, R. Below, and S. Ponserre, "Annual Disaster Statistical Review: The Number and Trends." Brussels: CRED, 2013.

[75]   H. Nancy, W. John, M. Robin, K. Ram, K. John, B. Craig, S. Jeff, K. Susan, G. Kevin, and E. Andrea Vann, "Information Sharing Guidebook for Transportation Management Centers, Emergency Operations Centers, and Fusion Centers," Transportation Research Board, FHWA-HOP-09-003, Jun. 2010.

[76]   Y. Ran, "Considerations and Suggestions on Improvement of Communication Network Disaster Countermeasures After the Wenchuan Earthquake," *Commun. Mag. IEEE*, vol. 49, no. 1, pp. 44 –47, 2011.

[77]   K. Mase, "How to Deliver Your Message from/to a Disaster Area," *Commun. Mag. IEEE*, vol. 49, no. 1, pp. 52 –57, 2011.

[78]   K. Mase, N. Azuma, and H. Okada, "Development of an Emergency Communication System for Evacuees of Shelters," in *Procdings of the Wireless Communications and*

REFERENCES

Networking Conference (WCNC), 2010, pp. 1–6.

[79]   A. Torok, B. Mezny, and P. Laborczi, "Traffic Information Dissemination in Vehicular Ad Hoc Networks," in *Mobile Ad-Hoc Networks: Applications*, X. Wang, Ed. InTech, 2011.

[80]   A. J. DeBlasio, T. J. Regan, M. Zirker, K. Fichter, K. Lovejoy, and D. Morin, "The Effect of Catastrophic Events on Transportation Systems Operations and Maintenance," DOT-VNTSC-FHWA-04-03, 2004.

[81]   C. Davison, D. Massaguer, L. Paradis, M. R. Rahimi, and B. Xing, "Practical Experiences in Enabling and Ensuring Quality Sensing in Emergency Response Applications," pp. 388–393, 2010.

[82]   McGhee, Catherine C., and Matthew C. Grimes, "An Operational Analysis of the Hampton Roads Hurricane Evacuation Traffic Control Plan," presented at the Proceedings of the 86th Annual Meeting of the Transportation Research Board, 2007.

[83]   "Emergency Response Transport Management: Managing Transportation Systems During Disasters," *TDM Encyclopedia*, 2010. [Online]. Available: http://www.vtpi.org/tdm/tdm124.htm. [Accessed: 13-Jul-2011].

[84]   R. Johnson, "GIS Technology for Disasters and Emergency Management," 2000, p. 12.

[85]   C. W. W. Ng and D. K. W. Chiu, "e-Government Integration with Web Services and Alerts: A Case Study on an Emergency Route Advisory System in Hong Kong," in *Proceedings of the 39th Annual Hawaii International Conference on System Sciences (HICSS)*, 2006, vol. 4, p. 70b– 70b.

[86]   N. Owens, A. April, S. Paul, M. Carol, P. Sullivan, N. Diane, B. Rebecca, and T. Todd, "Traffic Incident Management Handbook," 8301 Greensboro Drive McLean, VA 22102, Science Applications International Corporation (SAIC), Technical Report FHWA-HOP-10-013, 2010.

[87]   K. C. Vasconez and M. Kehrli, "Highway Evacuations in Selected Metropolitan Regions: Assessment of Impediments," 2010.

[88]   D. A. McEntire, *Comparative Emergency Management: Understanding Disaster Policies, Organizations, and Initiatives from Around the World*. FEMA, 2009.

[89]   P. Langdon and I. Hosking, "Inclusive Wireless Technology for Emergency Communications in the UK," *Int. J. Emerg. Manag.*, vol. 7, no. 1, p. 47, 2010.

[90]   S. Aravindan, P. Ganesh, K. D. Rajan, and M. Manivel, "Hydrogeochemical Mapping in Upper Gadilam River Basin Using GIS Technique, Tamil Nadu, India," presented at the Proceedings of the 29th Asian Conference on Remote Sensing (ACRS), 2008.

[91]   Y. Kumar, H. Upadhyay, and K. Kumar, "GIS Technology : Boon for Disasters and

REFERENCES

Emergency Management," *Int. J. Res. IT Manag.*, vol. 2, p. 8, 2012.

[92]   C. Gabriel, "Design Criteria in Government Institutional GIS (GIGIS)," Cairo, Egypt, 2005.

[93]   Department of Transportation, Joint Program Office for Intelligent Transportation Systems and Federal Transit Administration, "Incident Management Successful Practices : A Cross Cutting study : Improving Mobility and saving Lives." U.S. Dept. of Transportation, Washington DC, 2000.

[94]   Z. P, W. I, I. B, K. U. Leuven, M. E, and H. D, "An Overview of Incident Management Projects in the Netherlands," 1998.

[95]   C. Yue-ming, G. Hui, and S. Gang, "Emergency Management System for Major Traffic Accidents Based on New Model and Algorithms," in *International Forum on Computer Science-Technology and Applications (IFCSTA)*, 2009, vol. 2, pp. 367–371.

[96]   S. C. Tignor, L. L. Brown, J. L. Butner, R. Cunard, S. C. Davis, E. L. Fischer, M. R. Kehrli, P. F. Rusch, W. S. Wainwright, and H. G. Hawkins, "Innovative Traffic Control : Technology and Practice in Europe," FHWA-PL-99-021, 1999.

[97]   Bergmann Associates and Monroe County Department of Transportation, "Monroe County New York: I.T.S. Camera Deployment & Systems Integration Evaluation," 2006.

[98]   S. L. Kolb, J. L. Hibbard, and K. R. Alff, "Georgia's Call Box Project: Evaluation and Future Deployment Recommendations," presented at the Proceedings on the ITS Americas Connecting Meeting, Miami, USA, 2001.

[99]   R. P. Maccubbin, B. L. Staples, F. Kabir, C. F. Lowrance, M. R. Mercer, B. H. Philips, and S. R. Gordon, "Intelligent Transportation Systems Benefits, Costs, Deployment, and Lessons Learned : 2008 update," FHWA-JPO-08-032, 2008.

[100]   A. G. Bruzzone, E. Briano, and M. Massei, "Simulating Transportation Over a Wide Area During a Regional Crisis," in *Proceedings of the 38th Conference on Summer Computer Simulation*, Calgary, Canada, 2006.

[101]   F. Longo, "Emergency Simulation: State of the Art and Future Research Guidlines," *Society for Modeling and Simulation International (SCS)*, vol. 1, no. 2, p. 8, 2010.

[102]   S. Kanala, R. Lephiew, S. Ramaswamy, and R. Seker, "An Ontology-driven Incident Management System for Scenario Analysis of Disasters," in *Summer Computer Simulation Conference, SCSC*, USA, 2008, pp. 201–204.

[103]   M. R. Carter, M. P. Howard, N. Owens, D. Register, J. Kennedy, K. Pecheux, and A. Newton, "Effects of Catastropic Events on Transportation System Management and Operations," Washington, DC, USA, FHWA-JPO-05-042, 2002.

[104]   C. Zimmerman, P. Bolton, M. Raman, T. Kell, S. Unholz, and C. Bausher, "Communicating with the Public Using ATIS During Disasters_ A Guide for Practitioners,"

REFERENCES

FHWA-HOP-07-068, 2007.

[105] C. Cluett, F. Kitchener, D. Shank, L. Osborne, and S. Conger, "Integration of Emergency and Weather Elements into Transportation Management Centers," Washington, DC, USA, FHWA-HOP-06-090, 2006.

[106] I. Lequerica, M. G. Longaron, and P. M. Ruiz, "Drive and Share: Efficient Provisioning of Social Networks in Vehicular Scenarios," *Commun. Mag. IEEE*, vol. 48, no. 11, pp. 90 –97, 2010.

[107] O. Baujard, "Development of Equipment and Telecommunications Networks in Europe," in *Proceedings of the 15th International Conference on Telecommunications Energy (INTELEC)*, 1993, vol. 1, pp. 485 – 487.

[108] S. Lan, "Disaster Management Plan," in *Semiconductor Manufacturing Technology Workshop, 2002*, 2002, pp. 219 – 226.

[109] T. J. Pultz and R. A. Scofield, "Applications of Remotely Sensed Data in Flood Prediction and Monitoring: Report of the CEOS Disaster Management Support Group flood team," in *Geoscience and Remote Sensing Symposium (IGARSS)*, 2002, vol. 2, pp. 768 – 770.

[110] M. D. of E. Management, M. E. M. Agency, M. E. M. Agency, F. E. M. Agency, and Natural Resources Conservation Service, "Natural Hazards Mitigation Planning: A Community Guide." 2003.

[111] M. E. Baird, "Freight Transportation and Emergency Management: Profiles of Three Stakeholder Groups," presented at the Centre of International Freight Transportation Studies (CIFTS), 2010, p. 99.

[112] T. L. Moe and P. Pathranarakul, "An integrated Approach to Natural Disaster Management: Public Project Management and its Critical Success Factors," *Disaster Prev. Manag.*, vol. 15, no. 3, pp. 396–413, 2006.

[113] A. Meissner, T. Luckenbach, T. Risse, T. Kirste, and H. Kirchner, "Design Challenges for an Integrated Disaster Management Communication and Information System," in *Information System (DIREN)*, 2002.

[114] W. B. Rudman, R. A. Clarke, and J. F. Metzl, "Emergency Responders: Drastically Underfunded, Dangerously Unprepared," *Council on Foreign Relations*.

[115] G. Hossan, M. Ghowdhury, and I. Kushchu, "Prospects of Using m-Technologies for Disaster Information Management in Bangladesh and other LDCs," presented at the EURO mGOV, Brighton, UK, 2005, p. 11.

[116] J. Munodawafa, "Role of Telecommunications and ICTs in Disaster Management," presented at the ManagementManagementITU Southern and East Africa Workshop on the use of Telecommunications/ICT for Disaster Management: Savings Lives, Lusaka, Zambia, 2008.

[117] Wharman, "Social Media in Disasters and Emergencies," USA, Aug-2010.

REFERENCES

[118]   Asian and Pacific Training Centre for Information and Communication Technology for Development, *ICT for Disaster Risk Reduction: An Overview of Trends, Practices and Lessons*. Prevention Web, 2010.

[119]   A. M. Townsend, M. L. Moss, and R. F. Wagner, "Telecommunications Infrastructure in Disaster: Preparing Cities for Crisis Communications," 2005.

[120]   "Today in Earthquake History: Sichuan 2008," *Seismo Blog*. [Online]. Available: http://seismo.berkeley.edu/blog/seismoblog.php/2009/05/12/today-in-earthquake-history-sichuan-2008. [Accessed: 03-Jun-2012].

[121]   S. Mobarek, "Use of Mobile Infrastructure in Disaster Recovery," 2007, p. 10.

[122]   R. E. Krock, "Lack of Emergency Recovery Planning is a Disaster Waiting to Happen," *Commun. Mag. IEEE*, vol. 49, no. 1, pp. 48 –51, 2011.

[123]   J. R. Otukei, "GIS for Disaster and Harzard Management." GIS for urban and regional development, 2008.

[124]   L. Hogie, "Mobile Ad Hoc Networks: Modelling, Simulation and Broadcast-based Applications," PhD Thesis, University of Le Havre, France, 2007.

[125]   A. Fujihara and H. Miwa, "Effect of Traffic Volume in Real-Time Disaster Evacuation Guidance Using Opportunistic Communications," in *Proceedings of the 4th International Conference on Intelligent Networking and Collaborative Systems (INCoS)*, 2012, pp. 457–462.

[126]   M. A. Serhani and Y. Gadallah, "A Service Discovery Protocol for Emergency Response Operations Using Mobile Ad Hoc Networks," presented at the Proceedings of the 6th International Conference on Advanced Telecommunications (AICT), 2010, pp. 280–285.

[127]   M. J. Piran, G. R. Murthy, and G. P. Babu, "Vehicular Ad Hoc and Sensor Networks; Principles and Challenges," *arXiv:1108.2776*, Aug. 2011.

[128]   DARTS Lab, "Vehicular Ad-Hoc Network." [Online]. Available: http://darts.cse.nd.edu/projects/vanets/.

[129]   S. A. Mohammad, A. Rasheed, and A. Qayyum, "VANET Architectures and Protocol Stacks: A Survey," in *Communication Technologies for Vehicles*, Springer Berlin Heidelberg, 2011, pp. 95–105.

[130]   Z. Yahya and S. Masud, "Communications in Vehicular Ad Hoc Networks," in *Mobile Ad-Hoc Networks: Applications*, InTech, 2011.

[131]   A. Boukerche, H. A. B. F. Oliveira, E. F. Nakamura, and A. A. F. Loureiro, "Vehicular Ad Hoc Networks: A New Challenge for Localization-Based Systems," *Comput. Commun.*, vol. 31, no. 12, pp. 2838–2849, 2008.

[132]   S. McMillan, G. Koorey, and A. Nicholson, "Incident Management Modelling using

REFERENCES

Microsimulation with Adaptive Signal Control," in *Proceedings of the 10th ITS Asia-Pacific Forum*, Bangkok, Thailand, 2009, p. 4pp.

[133] S. R. A. Rizvi, S. Olariu, M. E. Rizvi, and M. C. Weigle, "A Traffic Chaos Reduction Approach for Emergency Scenarios," presented at the The International Conference on Performance, Computing, and Communications (IPCCC), 2007, pp. 576–578.

[134] S. R. Rizvi, M. C. Weigle, and M. E. Rizvi, "In VANETs for Rirst Responders," 2008.

[135] J.-S. Park, U. Lee, S. Y. Oh, M. Gerla, and D. S. Lun, "Emergency Related Video Streaming in VANET Uing Network Coding," Los Angeles, CA, USA, 2006, pp. 102–103.

[136] Y.-T. Tseng, R.-H. Jan, C. Chen, C.-F. Wang, and H.-H. Li, "A Vehicle-Density-Based Forwarding Scheme for Emergency Message Broadcasts in VANETs," in *Proceedings of the 7th International Conference on Mobile Adhoc and Sensor Systems (MASS)*, 2010, pp. 703–708.

[137] A. Buchenscheit, F. Schaub, F. Kargl, and M. Weber, "A VANET-Based Emergency Vehicle Warning System," presented at the Vehicular Networking Conference (VNC), 2009, pp. 1–8.

[138] M. Satyanarayanan, "Mobile Computing: the Next Decade," in *Proceedings of the 1st Workshop on Mobile Cloud Computing; Services: Social Networks and Beyond*, New York, NY, USA, 2010, pp. 5:1–5:6.

[139] M. L. Habib, "Mobile Computing."

[140] J. T. B. Fajardo and C. M. Oppus, "A Mobile Disaster Management System Using the Android Technology," *WTOC*, vol. 9, no. 6, pp. 343–353, 2010.

[141] R. Samarajiva and N. Waidyanatha, "Two complementary mobile technologies for disaster warning," *info*, vol. 11, no. 2, pp. 58–65, 2009.

[142] E. Fekpe and S. Collins, "Evaluation of Intelligent Transportation Infrastructure Program (ITIP) in Pittsburgh and Philadelphia, Pennsylvania," 2003.

[143] H. Purohit, A. Hampton, V. Shalin, A. Sheth, and J. Flach, "Framework for the Analysis of Coordination in Crisis Response," Feb-2012.

[144] T. Falco, "Taking Social Media Public: Social Media for Successful Citizen Relationship Management." IBM Global Services, 2011.

[145] B. R. Lindsay, "Social Media and Disasters: Current Uses, Future Options, and Policy Considerations." Congressional Research Service, Sep-2011.

[146] S. Smaldone, L. Han, P. Shankar, and L. Iftode, *RoadSpeak: Enabling Voice Chat on Roadways Using Vehicular Social Networks*. 2008.

[147] American National Red Cross, "Web Users Increasingly Rely on Social Media to Seek

REFERENCES

Help in a Disaster." 2010.

[148]   P. M. Figliola and G. Stevens, *Text and Multimedia Messaging: Emerging Issues for Congress*. DIANE Publishing.

[149]   B. Leonard, *2000 Emergency Response Guidebook: A Guidebook for First Responders During the Initial Phase of a Dangerous Goods/Hazardous Materials Incident*. DIANE Publishing, 2000.

[150]   Barton-Aschman Associates, Inc. and U.S. Department of Transportation, Federal Highway Administration, "Vehicle Occupancy Determinators," Arizona Department of Transportation, USA, Final Report, 1989.

[151]   Y. Gu, "Integrating a Regional Planning Model (TRANSIMS) With an Operational Model (CORSIM)," Master thesis, Virginia Polytechnic Institute and State University, 2004.

[152]   F. Southworth, "Regional Evacuation Modeling: A State-of-the-Art Review," Center for Transportation Analysis, OAK Ridge National Laboratory ORNL-11740, Tennessee, 1991.

[153]   N. Levine and M. Wachs, "Factors Affecting Vehicle Occupancy Measurement," *Transp. Res. Part Policy Pract.*, vol. 32, no. 3, pp. 215–229, 1998.

[154]   European Environment Agency (EEA), "Occupancy Rates of Passenger Vehicles," 2010. [Online]. Available: http://www.eea.europa.eu/data-and-maps/indicators/occupancy-rates-of-passenger-vehicles/occupancy-rates-of-passenger-vehicles-1.   [Accessed: 11-Dec-2014].

[155]   V. V. Dixit and E. Radwan, "Optimal Scheduling of Evacuation Orders for Cities," in *Proceedings of the 8th Annual Meeting on Transportation Research Board*, Edinburgh, UK, 2009.

[156]   K. S. Perumalla and M. Beckerman, "An Analysis Approach to Large-Scale Vehicular Network Simulations," presented at the The Summer Computer Simulation Conference, California, USA, 2007.

[157]   B. Wolshon, *Transportation's Role in Emergency Evacuation and Reentry*. Transportation Research Board, 2009.

[158]   H. T. L. Pham, J. L. Pittman, and M. C. Court, "A Review of Simulation Modeling Methodologies for Large-Scale Evacuations," presented at the The Summer Computer Simulation Conference, Edinburgh, UK, 2008.

[159]   N. J. Garber and L. A. Hoel, *Traffic and Highway Engineering*, 3rd Edition. 2002.

[160]   I. S. P. Hoogendoorn, *Traffic Flow Theory and Simulation*, Lecture notes course vk4821. Delft: Delft University of Technology, 2007.

[161]   J. Barceló, P. Vortisch, M. Fellendorf, H. Hanabusa, R. Horiguchi, M. Kuwahara, P.

REFERENCES

Sykes, D. Garcia, J. L. Ferrer, J. Casas, T. Toledo, H. N. Koutsopoulos, M. Ben-Akiva, D. Krajzewicz, R. Liu, M. Florian, M. Mahut, I. Papamichail, and M. Papageorgiou, *Fundamentals of Traffic Simulation*, vol. 145. Spain: Springer, 2010.

[162]   W. F. Adams, "Road Traffic Considered as a Random Series," *J. ICE*, vol. 4, no. 1, pp. 121–130, 1936.

[163]   S. McMillan, G. Koorey, and A. Nicholson, "Incident Management Modelling Using Microsimulation with Adaptive Signal Control," 2009.

[164]   M. T. Alterawi, "Development of a Micro-simulation Model to Evaluate Shuttle-lane Roadwork Operations," PhD Thesis, University of Salford, UK, 2014.

[165]   J. Wardrop, "Some Theoretical Aspects of Road Traffic Research," *Proc. Inst. Civ. Eng. Part II*, vol. 1, no. 36, pp. 352–362, 1952.

[166]   L. A. Pipes, "An Operational Analysis of Traffic Dynamics," *J. Appl. Phys.*, vol. 24, no. 3, pp. 274–281, 1953.

[167]   G. F. Newell, "Mathematical Models for Freely-Flowing Highway Traffic," *Oper. Res.*, vol. 3, no. 2, pp. 176–186, 1955.

[168]   F. V. Webster, *Traffic Signal Settings*. H. M. Stationery Off., 1958.

[169]   R. Chandler, R. Herman, and E. Montroll, "Traffic Dynamics: Studies in Car Following," *Oper. Res.*, vol. 6, no. 2, pp. 165–184, 1958.

[170]   M. J. Lighthill and G. B. Whitham, "On Kinematic Waves. II. A Theory of Traffic Flow on Long Crowded Roads," *Proc. R. Soc. Lond. Ser. Math. Phys. Sci.*, vol. 229, no. 1178, pp. 317–345, 1955.

[171]   N. H. Gartner, C. Messer, A. K. Rathi, F. L. Hall, R. J. Koppa, R. W. Rothery, P. G. Michalopoulos, R. Kuhan, J. C. Williams, S. Ardekani, E. Hauer, B. Jamei, R. J. Troutbeck, W. Brilon, N. Rouphial, A. Tarko, J. Li, E. Lieberman, and A. K. Rathi, *Traffic Flow Theory*. USA: Transportation Research Board, 1975.

[172]   J. T. S. Al-Obaedi, "Development of Traffic Micro-Simulation Model for Motorway Merges with Ramp Metering," Ph.D., University of Salford, 2011.

[173]   P. Ryder, "The Use and Application of Microsimulation Traffic Models, Interim Advice Note (IAN 36/01)." Highwats Agency, 2001.

[174]   A. Arulselvan, "Network Model for Disaster Management," PhD Thesis, University of Florida, USA, 2009.

[175]   M. B. Abdjabbar, "Traffic Assignment of Transportation Network of City," PhD Thesis, Al-Mustansiriya University, Iraq, 2005.

[176]   Transport for London, "Micro-Simulation Modelling Guidance Note for TfL." 2003.

REFERENCES

[177]   SIAS, "S-Paramics Principle." 2009.

[178]   Purnawan, "Development of Traffic Micro-Simulation for On-Street Parking Facilities," PhD Thesis, Salford University, Manchester, UK, 2005.

[179]   T. J. Cova and J. P. Johnson, "Microsimulation of Neighborhood Evacuations in the Urban - Wildland Interface," *Environ. Plan. A*, vol. 34, no. 12, pp. 2211 – 2229, 2002.

[180]   S. Algers, E. Bernauer, M. Boero, L. Breheret, C. D. Taranto, M. Dougherty, K. Fox, and J.-F. Gabard, "Review of Micro-Simulation Models." Smartest, 1997.

[181]   SIAS, *S-Paramics Microsimulation Manual*. UK, 2007.

[182]   H. A. E. Al-Jameel, "Developing a Simulation Model to Evaluate the Capacity of Waeving Sections," Ph.D., Salford University, Manchester, UK, 2011.

[183]   P. Hidas, "Modelling Vehicle Interactions in Microscopic Simulation of Merging and Weaving," *Transp. Res. Part C Emerg. Technol.*, vol. 13, no. 1, pp. 37–62, 2005.

[184]   Z. Xiongfei, S. Qixin, H. Rachel, and R. Bin, "Network Emergency Evacuation Modeling: A Literature Review," in *Optoelectronics and Image Processing, International Conference on*, Los Alamitos, CA, USA, 2010, vol. 2, pp. 30–34.

[185]   T. J. Cova and J. P. Johnson, "Microsimulation of Neighborhood Evacuations in the Urban - Wildland Interface," *Environ. Plan. A*, vol. 34, no. 12, pp. 2211 – 2229, 2002.

[186]   R. L. Church and R. Sexton, "Modelling Small Area Evacuation: Can Existing Transportation Infrastructure Impede Public Safety?," University of California, Santa Barbara, USA, Final Report, 2002.

[187]   G. Cameron, B. J. N. Wylie, and D. McArthur, "Paramics: Moving Vehicles on the Connection Machine," in *Proceedings of the International Conference on Super Computing*, Los Alamitos, CA, USA, 1994, pp. 291–300.

[188]   C. Xie, "Evacuation Network Optimization: Models, Solution Methods and Applications," PhD Thesis, Cornell University, 2008.

[189]   Thinking Machines Corporation, *C* Programming Guide*. Cambridge, Massachusetts, 1993.

[190]   S. Gwynne, E. R. Galea, M. Owen, P. J. Lawrence, and L. Filippidis, "A Review of the Methodologies Used in the Computer Simulation of Evacuation from the Built Environment," *Build. Environ.*, vol. 34, no. 6, pp. 741–749, 1999.

[191]   G. Santos and B. E. Aguirre, "A Critical Review of Emergency Evacuation Simulation Models," in *Proceedings of Building Occupant Movement during Fire, National Institute of Standards and Technology*, 2004, p. 25.

[192]   Federal Emergency Management Agency (FEMA), "Application of the I-DYNEV

REFERENCES

system.' Five Demonstration Case Studies," 1985.

[193]   Y. Sheffi, H. Mahmassani, and W. B. Powell, "A Transportation Network Evacuation Model," *Transp. Res. Part Gen.*, vol. 16, no. 3, pp. 209–218, 1982.

[194]   B. Mei, "Development of Trip Generation Models of Hurricane Evacuation," Master thesis, Louisiana State University, 2002.

[195]   A. G. Hobeika and C. Kim, "Comparison of Traffic Assignments in Evacuation Modeling," *IEEE Trans. Eng. Manag.*, vol. 45, no. 2, pp. 192–198, 1998.

[196]   B. N. Janson, F. Southworth, M. M. Venigalla, and D. of Energy, *DYMOD: Towards Real Time, Dynamic Traffic Routing During Mass Evacuations*. Oak Ridge National Laboratory, 1992.

[197]   J. R. Stone, United States, and National Oceanic and Atmospheric Administration, *Hurricane Emergency Planning Estimating Evacuation Times for on-Metropolitan Coastal Communities*. Springfield, Va.: National Technical Information Service, 1983.

[198]   S. Bretschneider and A. Kimms, "A Basic Mathematical Model for Evacuation Problems in Urban Areas," *Transp. Res. Part Policy Pract.*, vol. 45, no. 6, pp. 523–539, 2011.

[199]   M. M. P., Urbanik, T., and D. E A., "CLEAR (calculated logical evacuation and response): A generic Transportation Network Model for the Calculation of Evacuation Time Estimates," Prepared for the Nuclear Regulatory Commission by Pacific Northwest Laboratory. NUREGICR-2504, Washington, USA, 1981.

[200]   E. Stern and Z. Sinuany-Stern, "A Behavioral-based Simulation Model for Urban Evacuation," *Reg. Sci. Assoc.*, vol. 66, no. 1, pp. 87–103, 1989.

[201]   A. F. Han, "TEVACS: Decision Support System for Evacuation Planning in Taiwan," *J. Transp. Eng.*, vol. 116, no. 6, pp. 821–830, 1990.

[202]   V. V. Dixit, S. Ramasamy, and E. Radwan, "Assessment of I-4 Contraflow Plans: Microscopic Versus Mesoscopic Simulation," *Transp. Res. Rec. J. Transp. Res. Board*, vol. 2041, no. -1, pp. 89–97, 2008.

[203]   Y. Liu, G.-L. Chang, Y. Liu, and X. Lai, "Corridor-Based Emergency Evacuation System for Washington, D.C.: System Development and Case Study," *Transp. Res. Rec. J. Transp. Res. Board*, vol. 2041, no. -1, pp. 58–67, 2008.

[204]   G. Theodoulou and B. Wolshon, "Alternative Methods to Increase the Effectiveness of Freeway Contraflow Evacuation," *Transp. Res. Rec.*, vol. 1865, pp. 48–56, 2004.

[205]   N. Zou, S.-T. Yeh, G.-L. Chang, A. Marquess, and M. Zezeski, "Simulation-Based Emergency Evacuation System for Ocean City, Maryland, During Hurricanes," *Transp. Res. Rec. J. Transp. Res. Board*, vol. 1922, no. -1, pp. 138–148, 2005.

[206]   E. Kwon and S. Pitt, "Evaluation of Emergency Evacuation Strategies for Downtown

REFERENCES

Event Traffic Using a Dynamic Network Model," *Transp. Res. Rec.*, vol. 1922, no. 1, pp. 149–155, Jan. 2005.

[207]   M. Ping, M. Feiyan, and Y. Ming, "A Knowledge-based Validation Method of Complex Simulation Models," in *Proceedings of the International Conference on Artificial Intelligence and Computational Intelligence*, Washington, USA, 2010, vol. 2, pp. 03–06.

[208]   "Master Plan of the City of Al-Ramadi, First Stage: Field Survey," Hydrosult Center for Engineering Planning (HCEP), Engineering Consultancy Bureau, Montreal, Canada, 2005.

[209]   "Master Plan of the City of Al-Ramadi, Second Stage: Analysis of Existing Situation, Regional Context and Major Development Issues," Hydrosult Center for Engineering Planning (HCEP), Engineering Consultancy Bureau- Mustansiriya University, Montreal, Canada, Nov. 2009.

[210]   "Master Plan of the City of Al-Huseneya, First Stage Analysis of Existing Situation, Regional Context and Major Development Issues," Hydrosult Center for Engineering Planning (HCEP), Engineering Consultancy Bureau, Montreal, Canada, 2011.

[211]   R. Mehmood, J. Crowcroft, S. H, and S. Smith, "Grid-Level Computing Needs Pervasive Debugging," in *In Procedings of the 6TH International Workshop on Grid Computing*, 2005.

[212]   S. Venkata, R. K. Rao, and V. Diwanji, "WiMax'ble Pervasive Cloud - Empowering Next Generation Intelligent Railway Infrastructure," in *Proceedings of the 3rd International Conference on Communication Technologies for Vehicles*, Oberpfaffenhofen, Germany, 2011, pp. 58–68.

[213]   C. Lustri, "Continuum Modelling of Traffic Flow." 2010.

[214]   A. M. Vegni and T. D. C. Little, "A Message Propagation Model for Hybrid Vehicular Communication Protocols," in *2010 7th International Symposium on Communication Systems Networks and Digital Signal Processing (CSNDSP)*, 2010, pp. 382–386.

[215]   N. Mejri, F. Kamoun, and F. Filali, "Cooperative Infrastructure Discovery Through V2X Communication," in *Proceedings of the 9th Annual Mediterranean on Ad Hoc Networking Workshop (Med-Hoc-Net)*, 2010, pp. 1–8.

[216]   Ireland's Leading Independed Land Use and Transport Planning Consultancy, "OmniTrans Modelling," 2011. [Online]. Available: http://www.iltp.ie/services/trafficmodelling/omnitans.html. [Accessed: 15-Dec-2013].

[217]   P. Shen, "Efficient Methods for Trip Generation and Distribution Forecasts: A Case Study," presented at the The 64th Annual Meeting on Compendium of Technical Papers, 1994.

[218]   A. E. Haghani and A. Mohasel Afshar, *Supply chain management in disaster response*. University Park, Penn.: Mid-Atlantic Universities Transportation Center, 2009.

REFERENCES

[219]   P. Pretorius, S. Anderson, K. Akwabi, B. Crowther, Q. Ye, N. Houston, and A. V. Easton, "Interview and Survey Results: Assessment of the State of the Practice and State of the Art in Evacuation Transportation Management," Federal Highway Administration, U.S. Department of Transportation, USA, Final Report, 2006.

[220]   Kimley-Horn Associates, Inc., "Emergency Evacuation Strategy Plan," Arezona, Final Report, 2004.

[221]   H. Joshi, R. Seker, C. Bayrak, S. Ramaswamy, and J. Connelly, "Ontology for Disaster Mitigation and Planning," in *Summer Computer Simulation Conference, SCSC*, USA, 2007.

[222]   X. Chen and F. B. Zhan, "Agent-Based Modelling and Simulation of Urban Evacuation: Relative Effectiveness of Simultaneous and Staged Evacuation Strategies," *J. Oper. Res. Soc.*, vol. 59, no. 1, pp. 25–33, 2006.

[223]   T. S. Glickman, "A Methodology for Estimating Time-of-Day Variations in the Size of A Population Exposed to Risk," *Risk Anal. Off. Publ. Soc. Risk Anal.*, vol. 6, no. 3, pp. 317–324, 1986.

[224]   Z. Alazawi, M. B. Abdljabar, S. Altowaijri, A. M. Vegni, and R. Mehmood, "ICDMS: An Intelligent Cloud Based Disaster Management System for Vehicular Networks," in *Communication Technologies for Vehicles*, Springer Berlin Heidelberg, 2012, pp. 40–56.

[225]   D. Handford and A. Rogers, "Modelling Driver Interdependent Behaviour in Agent-Based Traffic Simulations for Disaster Management," presented at the Proceedings of the 9th International Conference on Practical Applications of Agents and Multi-Agent Systems, 2011, pp. 163–172.

[226]   G. L. Hamza-Lup, K. A. Hua, M. Le, and R. Peng, "Dynamic Plan Generation and Real-Time Management Techniques for Traffic Evacuation," *IEEE Trans. Intell. Transp. Syst.*, vol. 9, no. 4, pp. 615–624, 2008.

[227]   S. A. Boxill and L. Yu, *An Evaluation of Traffic Simulation Models for Supporting ITS Development*. USA: Center for Transportation Training and Research, Texas Southern University, 2000.

[228]   P. Sykes and D. Bennett, "Including ITS in Microsimulation Models," in *Proceddings of the 7th International Conference on Intelligent Transportation Systems*, 2004, pp. 1018–1022.

[229]   M. P. Miska, "Microscopic Online Simulation for Real Time Traffic Management," TRAIL Research School, Netherlands, 2007.

[230]   SIAS Limited, *SNMP Reference Manual*. UK, 2011.

[231]   "Simple Network Management Protocol." Erlang Public, 2013.

[232]   N. Lövehagen and A. Bondesson, "Evaluating Sustainability of using ICT Solutions in

REFERENCES

Smart Cities – Methodology Requirements," in *Proceedings of the First International Conference on Information and Communication Technologies for Sustainability*, Zurich, 2013.

[233] "Smart Cities Study: International Study on the Situation of ICT, Innovation and Knowledge in Cities," The Committee of Digital and Knowledge-based Cities of UCLG, Bilbao, 2012.

[234] S. Bretschneider, *Mathematical Models for Evacuation Planning in Urban Areas*. Berlin, Heidelberg: Springer-Verlag, 2012.

[235] Z. Alazawi, O. Alani, M. B. Abdljabar, S. Altowaijri, and R. Mehmood, "A Smart Disaster Management System for Future Cities," in *Proceedings of the 2014 ACM International Workshop on Wireless and Mobile Technologies for Smart Cities*, USA, 2014, pp. 1–10.

[236] Z. Alazawi, O. Alani, M. B. Abdljabar, and R. Mehmood, "An Intelligent Disaster Management System based Evacuation Strategies," in *Proceedings of the 9th International Symposium on Communication Systems, Networks Digital Signal Processing (CSNDSP)*, Manchester, UK, 2014, pp. 673–678.

[237] Z. Alazawi, O. Alani, M. B. Abdjabbar, and R. Mehmood, "Transportation Evacuation Strategies Based on VANET Disaster Management System," in *Procedia Economics and Finance, ELESVIER*, Manchester, UK, 2014.

APPENDIX A

In Appendix A, we are going to present the different disaster areas situations selection.

Disaster No.	Nodes	Links blocked by a disaster, each link in both direction
1	11, 77, 104, 76	11:77, 77:104, 104:76
2	40, 83, 46, 89, 90	40:83, 83:46, 46:89, 89:90
3	34, 35, 148	34:35, 35:148
4	21, 142, 20, 121, 122, 135	21:142, 142:20, 20:121, 121:122, 22:135
5	19, 53, 143, 20, 121	19:53, 53:143, 143:20, 20:121
6	141z, 80, 31, 79, 23, 19, 26, 56, 25, 24, 144z, 21	141z:80, 80:31, 31:79, 79:23, 23:19, 19:26, 26:56, 25:26, 25:24, 24:144z, 144z:21
7	9, 10	9:10
8	21, 22, 23, 79, 31, 80, 141z, 28, 37	21:22, 22:23, 79:23, 79:31, 31:80, 80:141z, 141z:28, 141z:37, 28:37
9	135, 134, 143y, 126, 124, 15	135:134, 134:143y, 143y:126, 126:124, 124:15
10	81, 44, 58z, 33, 138z, 138y, 40	81:44, 81:58z, 58z: 33, 58z: 138z, 33:138y, 44:40
11	14, 15, 139z, 126	14:15, 139z:14, 139z:15, 15:126
12	78, 19, 23, 79, 31, 80, 141z, 28	78:19, 19:23, 23:79, 79:31, 31:80, 80: 141z, 141z:28

APPENDIX B

Appendix B: Different driver response percentages are plotted here.

Here, we present the different driver response percentages with both systems; traditional and intelligent disaster management system.
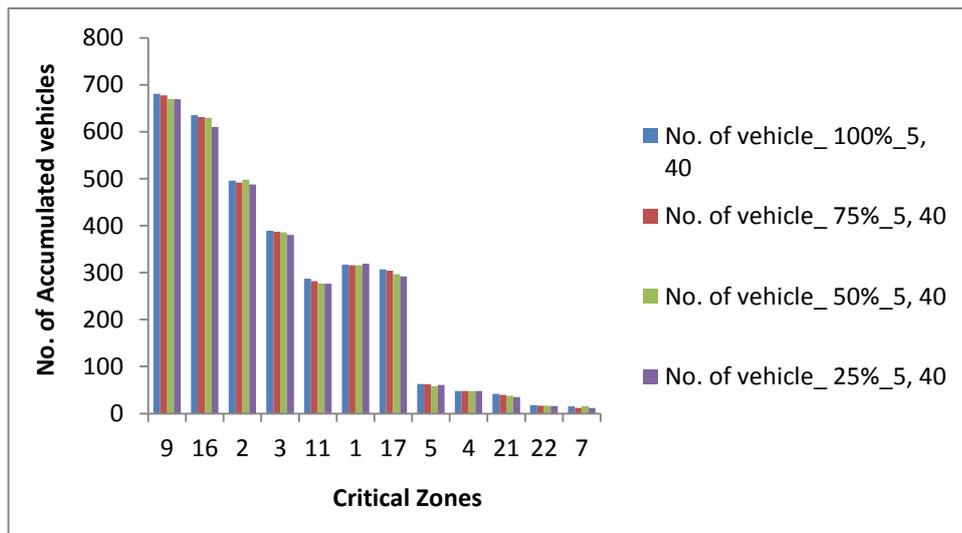
Figure B.1 Speed 5, 40_different response, new system
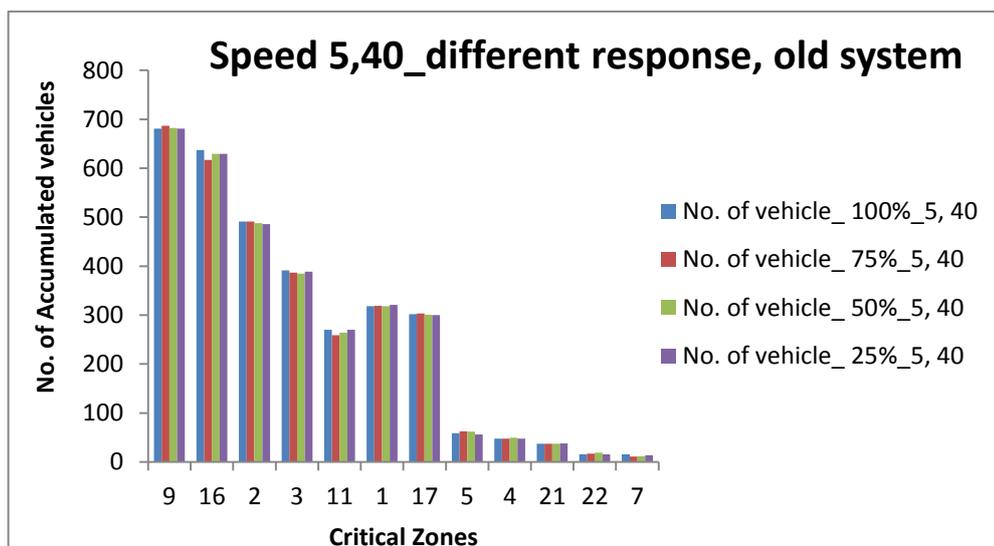
Figure B.2 Speed 5, 40_different response, traditional system
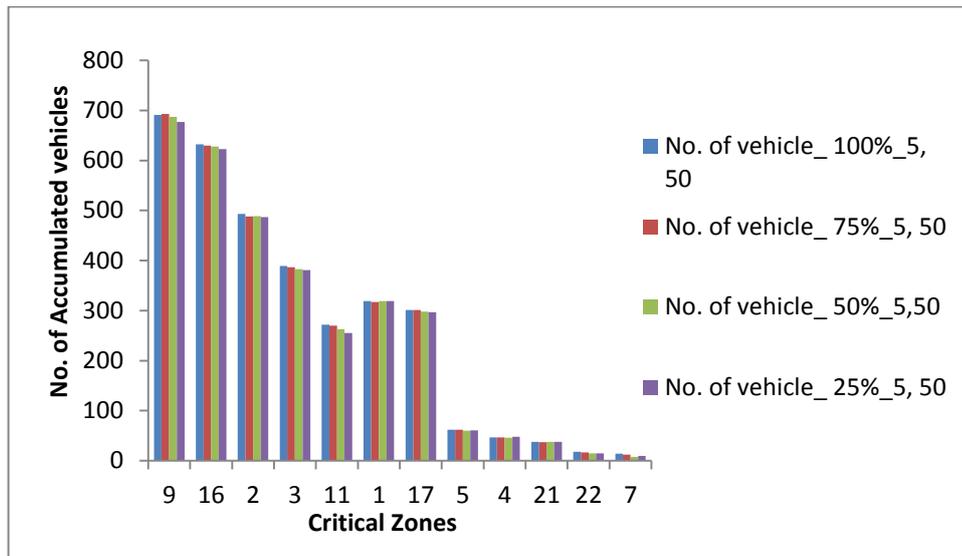
Figure B.3 Speed 5, 50_different response, new system
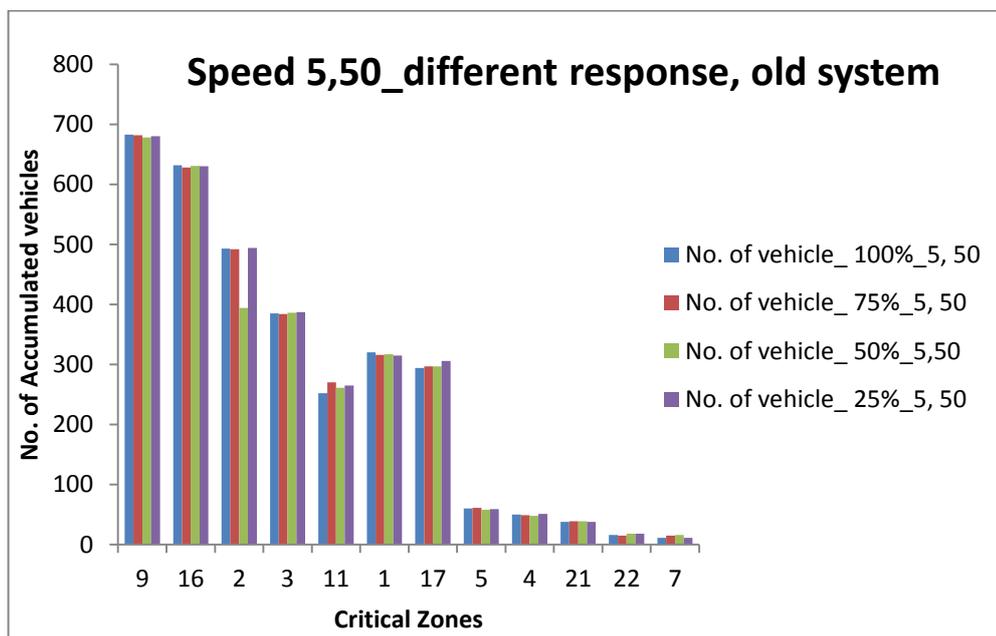

Figure B.4 Speed 5, 50_different response, traditional system
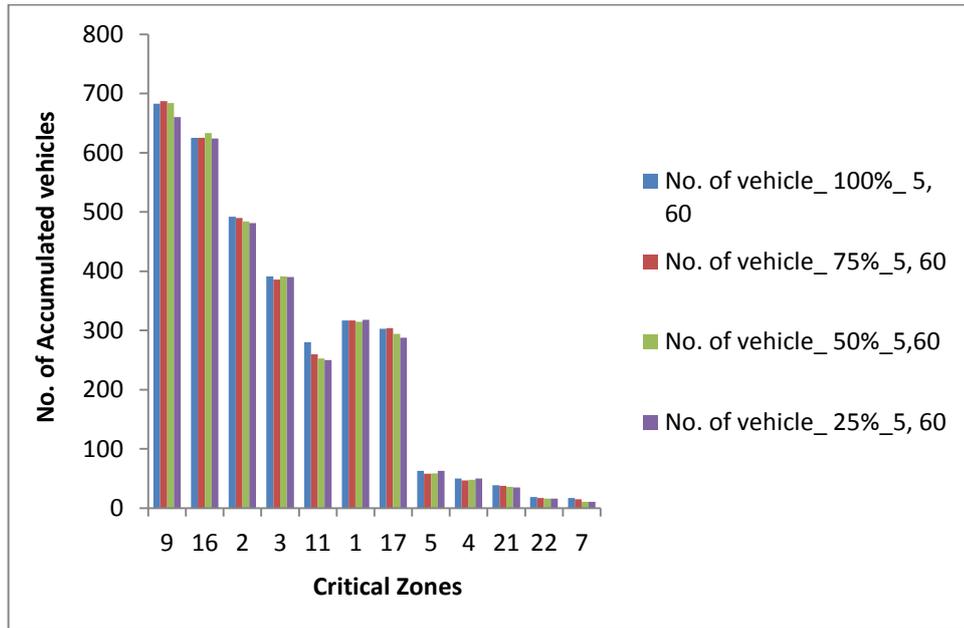
Figure B.5 Speed 5, 60_different response, new system
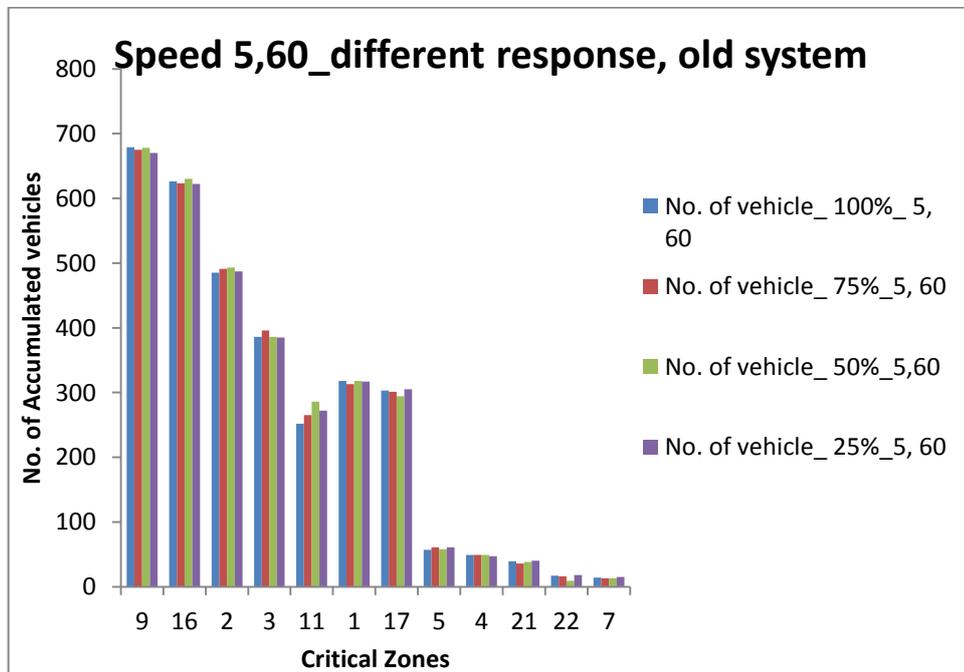
Figure B.6 Speed 5, 60_different response, traditional system
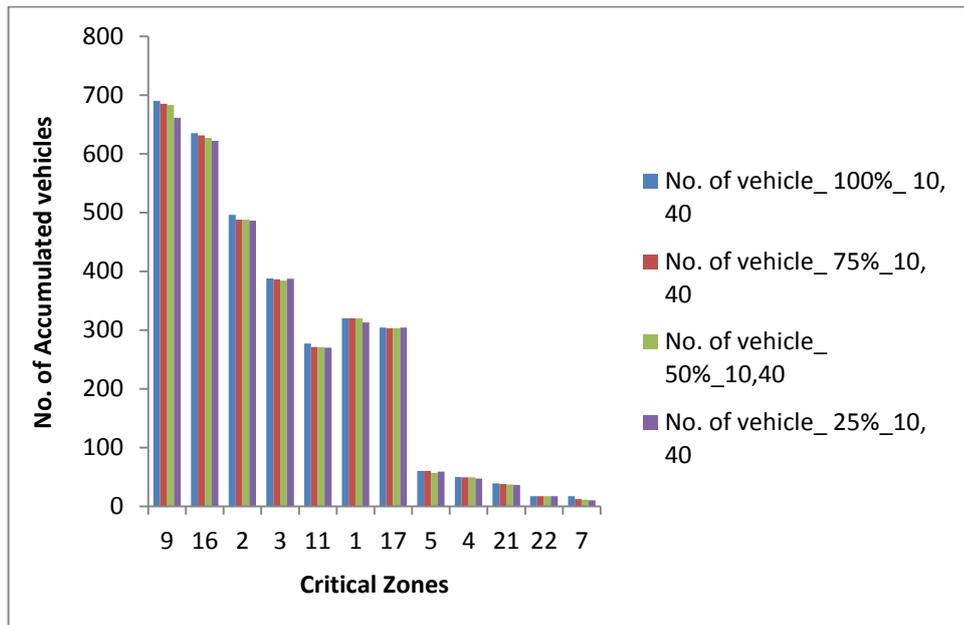
Figure B.7 Speed 10, 40_different response, new system
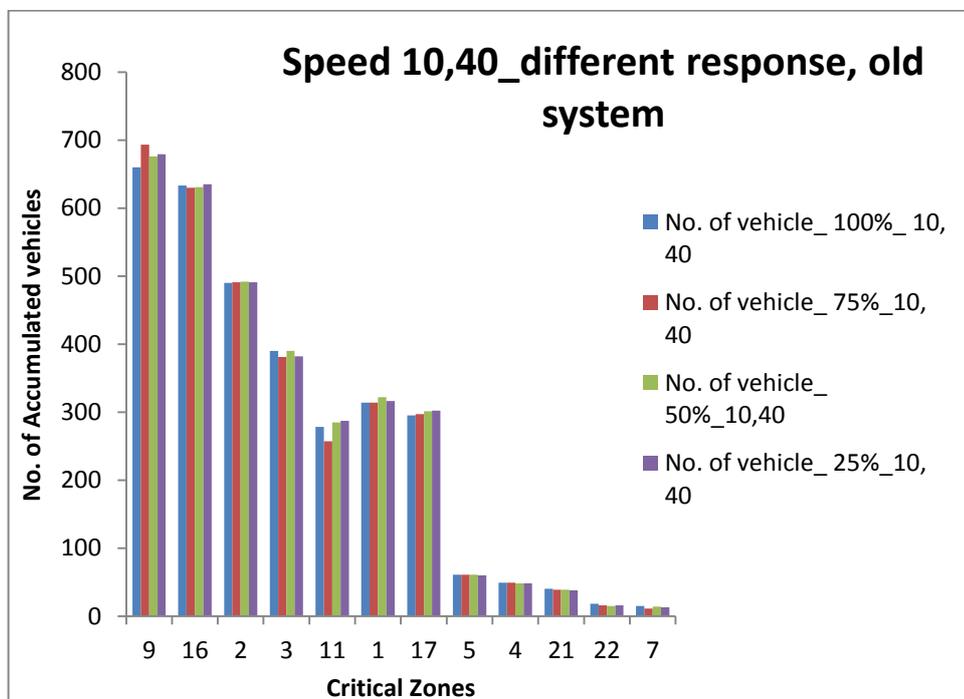
Figure B.8 Speed 10, 40_different response, traditional system
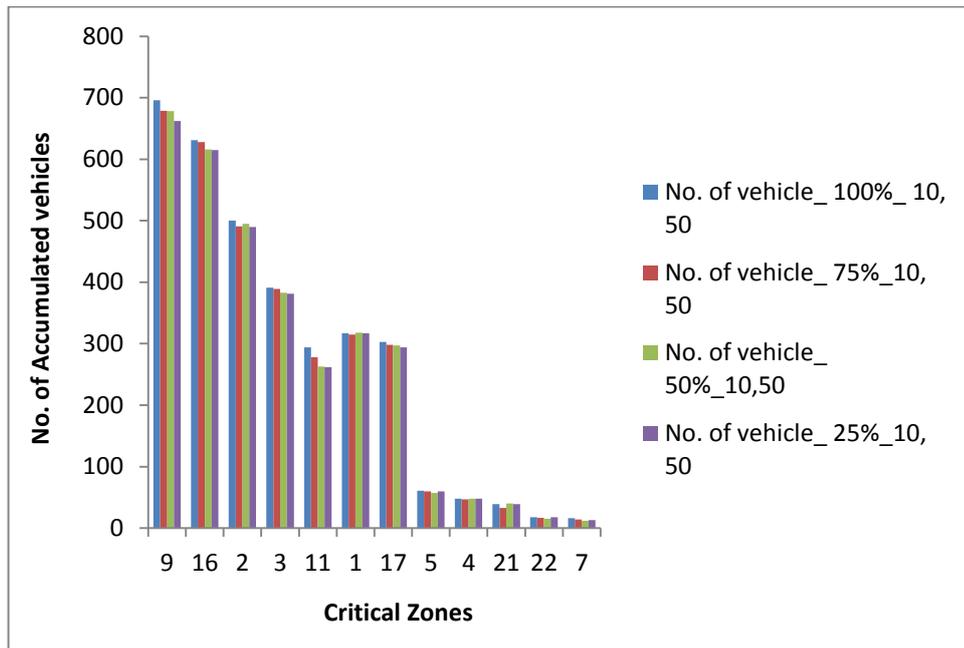
Figure B.9 Speed 10, 50_different response, new system
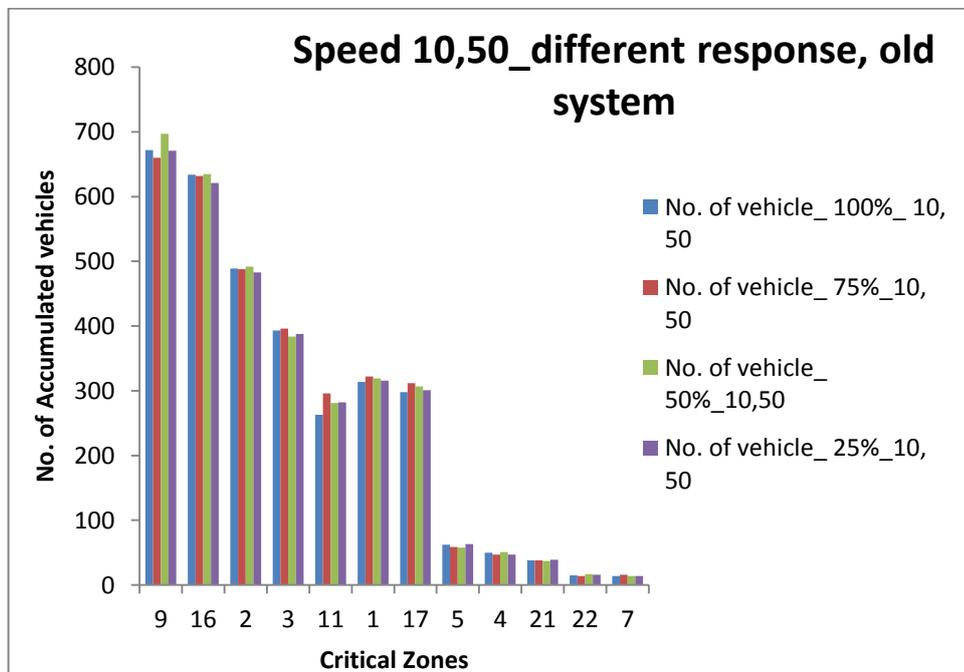
Figure B.10 Speed 10, 50_different response, traditional system
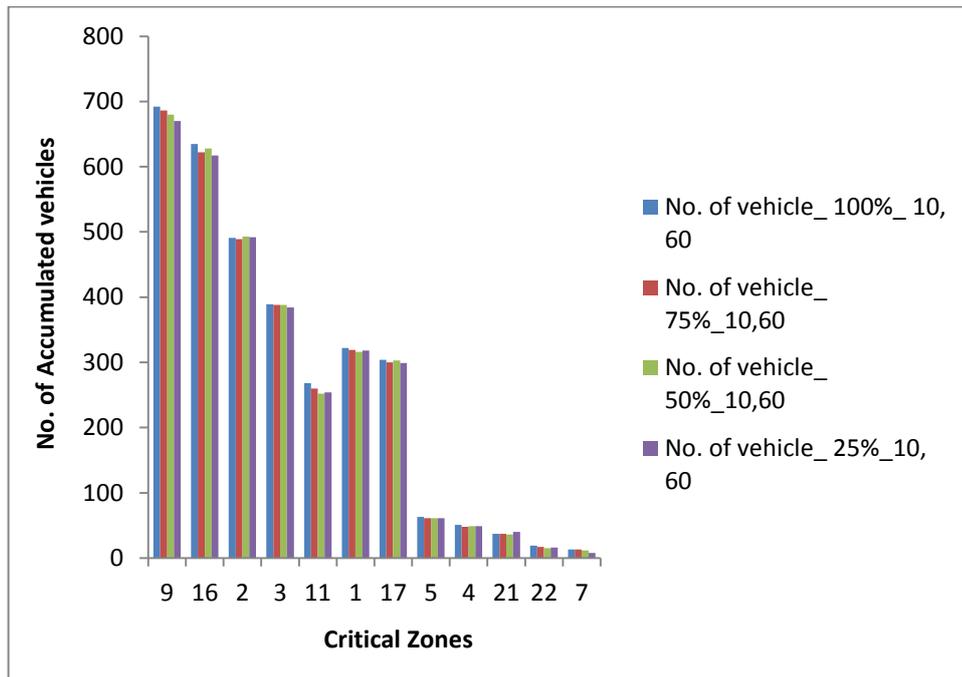
Figure B.11 Speed 10, 60_different response, new system
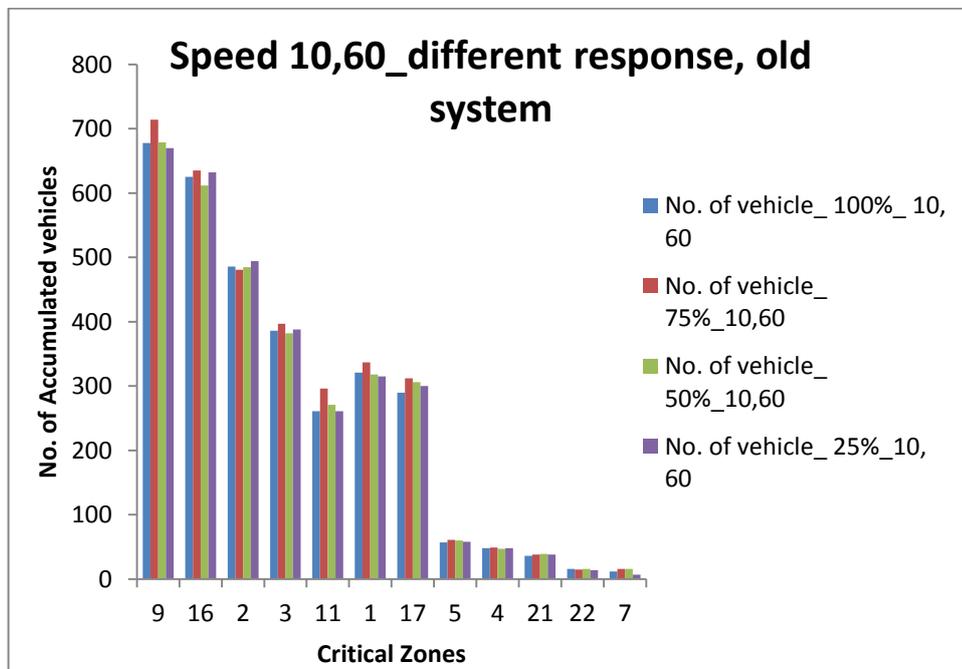
Figure B.12 Speed 10, 60_different response, traditional system