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Transportation Evacuation Strategies Based on VANET Disaster Management System

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Abstract

The September 2001 attacks and the 2011 Japan earthquake and tsunami disaster are examples of manmade and natural disasters which have revealed the importance of having a disaster management system in place. A great deal of advisory and policy documents need to be developed by various government authorities. The Intelligent Transportation Systems and Services (ITSS) are set to play a crucial role in responding to emergencies and large-scale disasters.

In previous works, 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. Also, we have developed a tool to examine previous proposed intelligent system performance in improving the transportation evacuation strategies, and Demand Strategy (DS) has been shown as one of the various evacuation strategies to measure the improvements. In this paper, we applied and evaluated another transportation evacuation strategy called Speed Strategy (SS), independently for traffic network. In addition, the driver response to the emergency situations and their behaviors in travel choices may be difficult to quantify theoretically, however, driver response to evacuation pre-plans is part of the tool design and we present the importance of this factor through various evacuation strategies.

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Keywords: Disaster Management System; Intelligent Transportation Systems; VANETs; Cloud Computing; Transportation Evacuation Strategies; Driver Response

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1. Introduction

The September 2001 attacks and the 2013 Philippines Typhoon Haiyan disaster have revealed the importance of having a disaster management system. Disasters, manmade and natural, result in huge human, social and financial losses. For example, in 2013, the World Disaster Report has stated that although recent 2012 reports show a reduction in the disaster damage, the damage of significant disasters, such as the 2010 Haiti earthquake, still reflects the lack of disaster systems and the need to increase the penetration of technologies, especially the information and communication technologies ("World Disasters Report 2013 - Focus on Technology and the Future of Humanitarian Action," 2013).

The shortcomings of the current evacuation procedures have not been stated adequately. We developed a tool to examine the proposed intelligent system (Alazawi et al., 2011) performance in improving the transportation evacuation strategies. In this paper, we aim at investigating the effect of devoting the proposed disaster management system including using in car systems; such as Vehicular Ad Hoc Networks (VANETs), to guide the evacuating vehicles from an affected area/s to one or more safe areas (evacuation areas) through applying different evacuation strategies in isolation. Driver behavior is considered in this tool and will be produced in this paper as well. This work covers the use of the intelligent transportation system (ITS) module in S-paramics in simulating these effects by propagating the warning messages including the information to vehicles in the simulation, at times selected by the analyst. Also, the driver response to the emergency situations and their behaviors in travel choices may be difficult to precisely quantifiy and predict in an analytical way. However, driver response to evacuation pre-plans is part of the tool design and we present the importance of this factor through various evacuation strategies.

This paper is organized as follows. A literature review relevant to driver response is presented in Section 1. Section 3 is dedicated to the intelligent disaster management system based evacuation strategies including the tool design and S-paramics ITS micro simulation method that we have used to model disaster and evacuation strategies scenarios. In Section 4, the evaluation results of different strategies are presented. Finally, Section 5 concludes the paper results.

2. Related work

The definition for Transportation Evacuation Strategies can be simply as "Moving the threatened people away from the dangerous area", it can be enhanced by implementing one/more evacuation schemes. The definition involves many important and complex steps that require intensive study to get the best selection of evacuation strategies that enables us to acheiev fewest possible losses. Section 2.1 provides the importance of driver response in the whole evacuation operation.

2.1. Driver Behavior

Driver behavior during evacuation strategies is very important and can be defined simply as "A successful evacuation plan reflects the high driver response percentage". Evacuee behavior 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 (Bretschneider, 2012) , therfore, we don't focus on rescue team behavior 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 affect the network evacuation. Responses to the emergency situations and behaviors in travel choices may be considered difficult and complicated to precisely quantify in the evacuation strategies (Xie, 2008). However, driver response to evacuation pre-plan was part of our tool 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.

3. The intelligent disaster management system based evacuation strategies

3.1. Tool design

We investigate the intelligent transportation system service including VANETs and Cloud Computing in improving the transport systems safety and performance, and seek to find out the optimum evacuation strategies in order to carry out day to day transport management and emergency response operations and hence to support a vehicular disaster managment system. The data received from various sources and communication gateways including ITS and VANETs, as shown in the vehicular architecture system in (Alazawi et al., 2011) and (Alazawi et al., 2012), and goes through an internal validation layer before it is accepted by the modeling and analysis layer.

In this paper, simulation models have been the tool of choice. We consider the simulation approach to introduce various strategies. S-paramics is widely regarded as a visual micro simulation software package which takes into account the major issues raised during the emergency response. Meanwhile, S-paramics possesses features that enable external software to communicate with a running simulation, to extract data from it, and to adjust parameters within it (SIAS Limited, 2011). S- paramics has been applied to obtain the clearing time estimates under various scenarios (Church and Sexton, 2002) and (Xiongfei et al., 2010). In this study, we focus on applying the intelligent disaster management system to obtain the optimum evacuation strategies.

3.2. S-Paramics ITS system

The S-paramics ITS system is designed to allow a controller to link to a running simulation, and take information from the simulation at pre-determined intervals. The advantages of using this system are, for example to adjust signal timings at junctions and to pass messages to vehicles in the simulation by exploiting the advanced communication technologies; ITS system, such as VANETs, distributing devices and by information on dynamic message signs (Sykes and Bennett, 2004). The system has been used in different applications as well as many other ad-hoc control applications, see (Sykes et al., 2010) and (Thomas et al., 2009).

The communications mechanism is called SNMP. The tool communication, ITS devices are the key elements is established through dispatching messages and this can be done by creating a controller for each lane/link over the entire network although that SIAS Paramics manual indicates that a controller is able to do the job for the entire city (SIAS, 2007). Also, selecting the position of the controller/s inside the network is crucial as it should be before the stop line of the link as it gives enough time to drivers to respond well to the messages/alarms passed. Once connection is established, the controller creates the links to the objects in the simulation it intends to manage or to use to collect data, and the tool is instructed to notify the controller when a fixed time has passed.

This simulation tool, a controller, which starts the simulation, links to it and has the ability to control the actions of vehicles at predetermined times. While some of the ITS technologies such as VANETs and the signal control applications respond directly to data taken from the ATM controller respond and act in a similar way to queue detection, here we intend to initially produce a one way controller which implements time based actions only.

The Spreadsheet is also an ideal tool for holding the required variables for the ITS actions. The Spreadsheet with running example is shown in Figure 1.

The interface for the controller is a Spreadsheet because it is accessible and the Visual Basic macro language 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. The effective data that could be obtained from the simulation software, S-Paramics, are: Speed; Flow; The number of vehicles to be released on a specified trip; Queue; Unreleased vehicles and Journey time.

The “Run simulation” button runs the requested number of runs of the specified model and may or may not log data as required. If the data is requested the simulation is run in batch mode; if it is not requested the simulation is run in visual mode. Various ranges of actions/strategies can be applied through the Spreadsheet and they are described in Table 1. The detail of the parameters for each strategy will vary with each action type, but will be set on the action row in one or more cells.

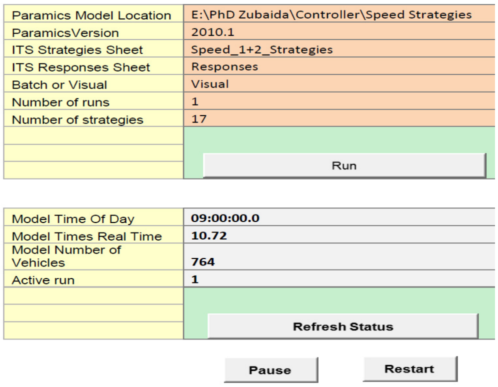

Fig.1. SNMP Spreadsheet

The controller is written in Visual Basic and makes calls to the SIAS supplied SNMP. The ITS device messages are composed of three elements, see Table 2. To increase the effectiveness of the implementation of this interface, real-time data are required (dynamic traffic data) which mainly depends on exploiting the ICT technologies proposed, i.e. data collected and dispatched by the V2V and V2I and other ITS devices. In other words, in this application, the advance technologies used such as the ITS device including VANETs are the key element as they control the actions of vehicles moving in the simulation affecting their wider responses. Different versions of this Spreadsheet will allow different strategy combinations to be tested and the results analyzed to investigate the effect of strategy choice, and the optimum time to implement it will be given in Section 4.

Table 1 Description of various strategies

Evacuation Strategies	Description
Demand	Modify the demand in the model for a particular trip to cut off the conflicting traffic.
Speed	Modify the speed limit on a set of links.
Lanes	Modify 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 car park to go to another. The model needs to be coded with the destination zone linked to a set of car parks and these are used as the stopping point.

Table 2 Elements of ITS messages

ITS messages	Main elements
A display message – purely for display	• Text and JPG image
An action message – to interpret the display message and provide an action for the vehicles	• Speed limit • Lane restrictions • Behavior changes (awareness and aggression or a headway modifier) • Route information; it include; Achieved speed on links, Waypoint delay information and Car park redirection
A response rate – to describe which vehicles take heed of the message	• Percentage of vehicles • Vehicles of specified types and specified destinations

4. System evaluation

Here, we are going to consider the proposed disaster management system [refenece], together with the controller developed to evaluate some evacuation strategies to verify their usefulness. Also we present the driver behavior performance on each strategy in this section. To investigate the tool design objective we demonstrate the tool using data from a real city which we refere to it as city X . This city is located in the United Kingdom and comprises 25 zones and 315 nodes. The transportation network of the city X is presented in Figure 2 (base situation). The network demand is accounted based on the Origin-Destination (O-D) matrix which has been used in Fratar model (Shen, 1994).

The numbers of trips in the O-D matrix are calculated in the mid-week period. From different accident potential risks; natural and man-made, 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. Figure 3 represents the snapshot for the disaster scenarios. We consider the incident hits the city at 8:00am at the rush hour, rush houre represents the maximum traffic volume which shows the maximum number of vehicles moving across the entire transport network, as we are able to test the tool in the worst conditions and thus enabling us to suggest and recommend the appropriate strategies.

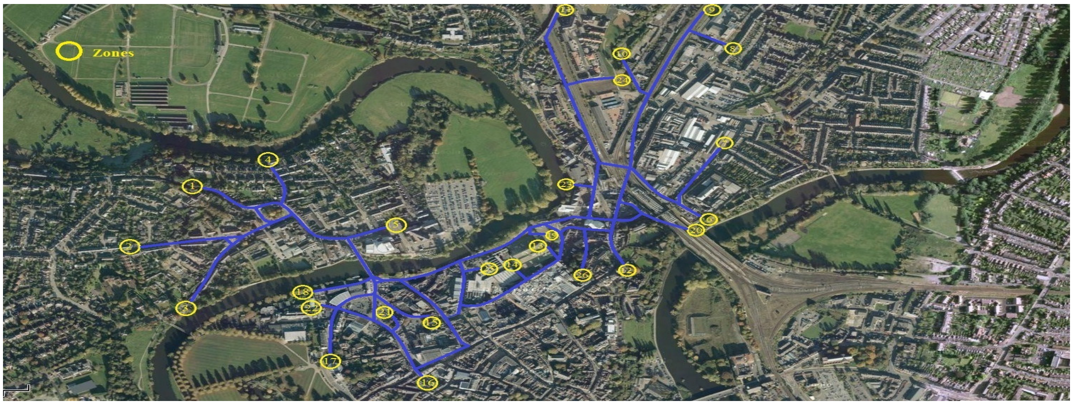

Fig. 2. City X transportation network in base situation

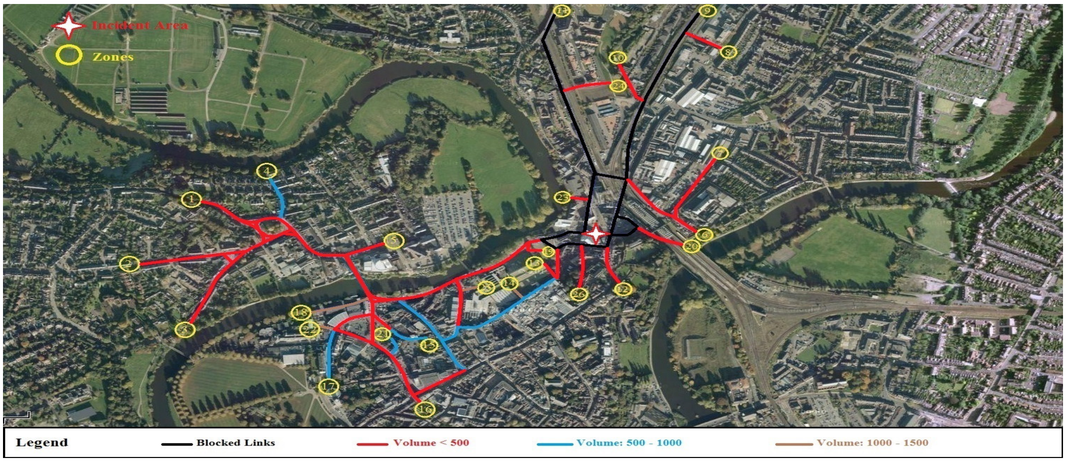

Fig. 3. The transportation network after the disaster hits the City X

Figure 3 shows the transportation network after the disaster hits the city X. The disaster divided the city into two major sub-networks, upper an lower parts. 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 couple of roads have volumes between 500 and 1000 vehicles per hour (represented by roads coloured in blue).

We assume the disaster hits 25 different areas and record harmful impact this is a repeat of the previous sentence, delete one. 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 3 shows the area of the worst accident. After a short time, 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 has begun to accumulate in many roads especially the links nearby the event area or stack in the original zones.

In this paper we consider an evacuation strategy entitled Speed Strategy (SS) and the driver behavior is assumed to reveal the importance of this factor, driver response. As a result, our intelligent disaster management system is selected to be in place which is able to present; send and receive the real-time data, and an evacuation plan is ordered. Different evacuation strategies can be applied such as Demand, Speed, Lane Reversal and Redirect strategies; see Table 1. The previously proposed intelligent system enables the disaster management centre to suggest and recommend a range of suitable evacuation strategies and there is an opportunity to change the strategy according to the real-time information.

4.1. Evacuation strategies

4.1.1. Speed Strategy, SS

In order to examine a broad scope of possible evacuation outcomes for the city X, multiple evacuation strategies can be modeled. The disaster centre has received and gathered the data collected from different sources. Subsequently, the centre aims to propagate the suitable strategy . In this work, we apply the Speed Strategy through around 90 scenarios, we change the critical input data in the speed sheet, see Table 3.

In a normal situation, most city links are limited to 30mph. However, after the disaster hits the city and vehicles start to move, panic results in anarchy. As a result, we recommend applying the intelligent disaster management system, means real-time network information, including different evacuation strategies. While in traditional 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 disaster area as quick as possible, and/or slow the speed for other links to prevent vehicle moving towards the disaster area and other affected links, see Table 3.

Table 3 Speed strategy sheet, example of various conditions

Speed limit, mph			
Increased	Decreased	Strategy start time, hh:mm	Driver response%
40	5	08:05	25
50	10	08:15	50
60		08:30	75
70			100

Also, from an analysis perspective, we are able to enter different start and end SS implementing time which represents the disaster management system's main contributions. In other words, it shows the advantages of the 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 paper for the first time. Four different percentages are used to present the importance of this element as it speeds the evacuation operation. Finally, we are able to use the conditions in Table 3 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 (Chen and Zhan, 2006). We believe that we can evaluate the network behaviour at 10-15mins intervals to give enough time to respond and obey the instructions. The process are 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.

4.2. Results and Discussion

Due to a disaster impact, a considerable number of vehicles is trapped and accumulated within the network. An effective evacuation strategies policy is demonstrated to control the traffic network. Table 4 shows the city X network while it is under the disaster impact and without any emergency system. An example of the SS implementation while changing the different speed conditions, such as increase and decrease the speed limit, applying different driver response, as shown in Table 4.

Table 4 Comparison of disaster impact and Speed Strategy implementation for some zones

Critical zone	No. of accumulative vehicles, veh/hr												
	Disaster impact scenario	Speed limit, mph, 100%						Speed limit, mph, 100%					
		40,5	50,5	60,5	40,10	50,10	60,10	40,5	50,5	60,5	40,10	50,10	60,10
9	696	670	691	683	683	690	686	678	669	684	685	679	680
16	625	628	645	625	622	625	618	633	631	633	631	628	628
2	477	489	499	492	488	490	491	493	492	481	488	500	493
3	377	386	397	381	388	391	386	394	389	391	384	383	388
11	249	272	284	258	271	263	252	283	278	253	277	278	260
1	310	317	322	317	320	317	319	321	316	315	320	318	316
17	324	288	327	301	299	297	299	303	298	294	303	303	303
5	59	61	64	63	60	57	61	63	59	59	57	61	61

Table 4 shows the vital role of some fundamental keys for the SS, as discussed earlier, 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 case of applying different speed limits for different network links, low speed 5 & 10 mph and high speed of 40, 50 & 60mph.

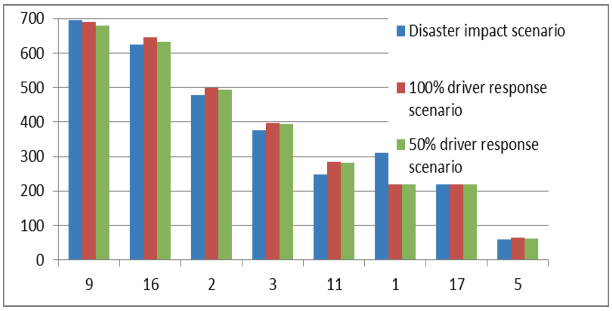

Figure 4. example of results which show the Speed strategy impact withing different conditions

Table 4 shows the improvement which can be achieved from applying the highest driver response, 100%, with the speed limit, 5 and 50mph. 100% driver responses follow the strategy order would lead to increase 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 incomplaince 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 4, which show the Speed Strategy positive impact through using different conditions is ploted in Fogure 4. 100 % driver response with speed of 5&50mph falls within a suitable range for different scenarios.

5. Conclusions

A greater penetration of ICT in ITS will play a critical role in disaster response and transportation management in order to minimize loss of human life, economic cost and disruption. In this paper, we used a tool to examine the effectiveness of an evacuation strategy entitled Speed Strategy. The tool assumes dynamic decision support evacuation. Because we apply the dynamic disaster system and evacuation strategies, significant improvements are achieved. The system was evaluated using the micro-simulation model known as S-Paramics ITS system to measure the effectiveness of the system in terms of improved disaster evacuation characteristics. In addition, the driver response is considered and evaluated. The results show big improvement while applying the SS in saving the human lives.. The results also show an improvement has been achieved in terms of the number of saved vehicles. The future work will focus on further analysis and validation of other disaster evacuation strategies.

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