An Intelligent Disaster Management System Approach to Evacuation Strategies

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Abstract. The importance of disaster management systems is undeniable and is unable to be underestimated because of the numerous manmade and natural disasters now days like the earthquake in Japan, the tsunami disaster in 2011 and the Hurricane Sandy in 2012. The Japan disaster estimated cost was more than 300 billion US dollar. The role of telecommunications and transport is an indispensable resource to manage disaster in averting the human life loss, economic cost and in controlling the disruption. Focusing on the emergency transporting systems, an emergency response system was proposed for disasters at various levels of scale. The system exploits the Information and Communication Technology (ICT) developments, in addition developing a new tool/model to assess the suggested intelligent disaster system within the transportation evacuation strategies performance. The Speed Strategy (SS) and Demand Strategy (DS) were evaluated separately and simultaneously, for traffic in urban networks. In this work the intelligent disaster system Intelligent which utilizes the Intelligent Transportation Systems (ITS) were employed. In other words, varied substitute technologies which includes VANETs (Vehicular Ad hoc Networks) and mobile technologies are applied to suggest and examine an evacuation strategy called (Destination Strategy) while using the proposed Intelligent Disaster Management System. The effectiveness of the current developed system was observed by comparing the modelled consequences of a disaster on the transport environment with that of when the disaster management was implemented. Moreover, a balance and improvement in the traffic flow with effortless evacuation was observed as an outcome of the developed current work along with the implemented Designation Strategy.

1. Introduction
Over the previous decades, a significant increase of the emergency response systems has been created as an outcome of the disasters from natural recourses or manmade recourses for example that occurs in September 2001 and Hurricane Sandy 2012. Disasters have always been a major source of risks to human and societies with unpredictable place, time of occurrence and scale of devastation. Disasters result in considerable economic and human loss each year throughout the globe. Besides hurricane Katrina, hurricane Sandy appears to have easily caused an estimated damage of $60 billion (£37billion) than any other in the history of US [1] and [2]. This has led to different new programs and legislations in many countries such as in the, but not limited, USA, Europe and Japan. See, for example [3] and [4].

The modern technologies such as Information and Communication Technologies (ICT) plays consequential duties in acknowledging and acting upon emergencies and reducing disturbance in addition to human and socioeconomic costs. An example on the developments in ICT was observed
previously, furthermore, the position of these technologies in Intelligent Transportation Systems is supposed to expand enormously. Transportation, a key public and government worry, affecting nearly all aspects of daily lives. Developed technologies such as vehicular, sensor and social networks in addition other unique nowadays technologies are allowing alternative potentials for transportation [5, 6]. We have witnessed a great occasion to observe and control the systems of transportation in real-time and at high granularity because of the vehicular and sensor networks that generate large quantities of exceptionally utilitarian and valuable data.

This work presents the capitalize of the grown evolution of the Information and Communication Technology to propose and evaluate an urban traffic network performance while applying an evacuation strategy called Destination Strategy and compare the network traffic situation without the strategy existence. The Strategy is evaluated by the suggested intelligent disaster management system. The currently used system models the consequences of an actual city affected by a disaster. Two different urban scenarios were modelled. The first one is disaster management that used traditional technologies and the second one by exploiting the intelligent vehicular based disaster management system. Both the scenarios insinuate contrast presents the performance this system in the following terms:

- The number of vehicles can be evacuated from point to safe point,
- The traffic flow, and
- A balanced use of transportation resources

The current manuscript is arranged so that summary of some technological applications, such as VANET, which have been used in the proposed system in Section II and Section III provides explanation to transportation evacuation strategies background. Sections IV and V presents the evaluation of the current system proposed in this work and the strategy result achievement followed by the conclusions and recommendations for further studies.

2. Literature review and Theoretical background

2.1 VANETs and Intelligent Transportation Systems
Humans have an instinctive desire for amusement, assurance, advancement, flexibility in transport, mobility, and defence. Such needs are paving the way to progress into the implementation of intelligent transport systems (ITS). Vehicular ad hoc networks (VANET) is an advance permitting technology for ITS. Normally, VANETs are established on fly by vehicles that have wireless communication features. "The participant nodes in VANET interact and cooperate with each other by direct communication with the nodes within range, by hoping messages through vehicles and roadside masts. Traditionally, data regarding traffic on a road is only accessible through inductive loops, cameras, roadside sensors and surveys. VANETs supply new venues for collecting real-time information from on board sensors on vehicles and for swift dissemination of information. Due to the fact that the information gathered from individual nodes participating in VANETs can be integrated together to form a real time picture of the road situation. Many new applications have been enabled through VANETs, though safety and transportation efficiency applications are the most crucial driver for VANETs. Lastly, there has been various ITS stakeholders such as governments, telecommunication companies and car manufacturers are operating in conjunction to make VANETs based ITS a reality" [7-9].

2.2 The Intelligent Emergency Response System
The "emergency evacuation" is defined 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” [10]. The communications performed an indispensable function in supervising, controlling and guiding the evacuation operation throughout disasters. Typically, during disasters transpire, humans in the affected region are required to follow information provided by the emergency agencies. The actual connections
start to move and transport the affected people to a safer place [11]. We developed an emergency system and Fig. 1 represents the framework of the Cloud-enabled vehicular emergency response system. The system comprises 3 key levels. The Cloud infrastructure layer acts as the foundation and the environment for the intelligent emergency response system. Numerous sources are used to obtain data in order to optimize the emergency response strategies, while the Intelligence Layer delivers the obligatory algorithms and computational models to aid it. Various information sources such as, smart phones, internet, social networks, roadside masts etc. are used by the system interface. Vehicles can interact with the gateways through car-to-car (C2C) or car-to-infrastructure (C2I) communications, as shown in Fig. 1. For instance, communication with a gateway can be obtained directly through the internet if accessible. Communication with other vehicles or road masts may be possible with the use of broadcast, point-to-point, or multi-hop communications.

![Architecture of the Emergency Response System](image)

Figure 1: Architecture of the Emergency Response System

3. Transportation evacuation strategies

In the course of disaster, evacuating is one crucial process that is essential among other processes also. Until now, an assortment of evacuation forms has been piloted and trailed, such as; Spontaneous Evacuation, Voluntary Evacuation, Mandatory or Directed Evacuation and Notice versus No-Notice Evacuation [12]. Meanwhile, evacuation strategies are affected considerably by some factors, one of the most important factor is the Average Vehicle Occupancy, explained simply as “How many persons are being transported by the private vehicles counted or surveyed as travelling in different geographic areas, on different types of roadways, for different trip purposes or at different times of the day” [13]. In addition, driver behaviour should be considered as an important factor which can alter the evacuation result significantly. In such scenarios, some drivers use their previous network memory (myopic) to estimate the traffic ahead. For that, people’s/driver’s reaction time to the occurrence is crucial and the average vehicle occupancy should be accounted [14].

In previous and present paper, to calculate the sum total of the time required for evacuation process, we presume that the technology of VANETs with the help of a virtual cloud infrastructure implemented in order to increase the possibility of minimizing the total time taken for evacuation and thereby increasing the chance to receive/deliver emergency messages between the control management unit and the driver[15].

A variety of strategies can be implemented and examined independently and simultaneously. We applied and evaluated two other different evacuation strategies in previous researches, see [16], [17]
and [18]. In this paper, the Destination Strategy is the main consideration as we assume it dominates the scenario/evacuation actions. Further actions/strategies can be seen in Table 1.

**TABLE 1. STRATEGIES FOR EVACUATION**

| Evacuation Strategies | Description |
|-----------------------|-------------|
| Signals               | To shut down a junction, set a red or green time on signal stages. The signalised junction should be coded with a closed stage and normal stage. The closed stage should be modelled such that it is never active while the model runs. Call the closed stage through the Spreadsheet as required. |
| Contra flow           | The lane capacity of a link should be doubled by opening a normally closed lane in one direction and barring a link in the other direction- which will probably have its kerb points shifted to overlap the now closed lane. |
| Demand                | The demand in the model should be modified for a particular trip to remove conflicting traffic |

4. the transportation network and the destination strategy

4.1. City X and its Transportation Network

A main urban area in the UK, situated in the middle of England. The estimated population in 2012 by the Office of National Statistics, based on a 2001 census, is 170,000. In this paper, we will mention some evacuation studies repeatedly that have been coordinated in this city and due to the sensitivity of the subject, we cannot mention the city by its name. Fig. 3 is the map highlighting the transportation network of the city, essential networks (consisting of nodes, zones, and links) and the city network. The city is divided into 26 zones and has been distributed within the map of the city as seen in Fig. 3.

Note also in Fig. 4 present are three different evacuation sites, evacuation areas 1, 2 and 3. Their intention is to supply a suitable and secure location for the population in case of major disasters resulting in people needing to be evacuated out of the city. The evacuation areas are selected in these specific positions because there is a highway that joins the local roads with the neighbouring city. Also, the area in some positions within the city is mostly a private property. Meanwhile we avoid some areas because they could be a desert or agriculture land which means that the area's connection of junctions is deficient in the situation where medical help is needed by the population.

4.2. The Emergency Strategy and Simulation Model

In few circumstances, it is economical and obligatory to engage in micro-sized traffic models, for instance, for evolving transport policies and procedures; this is due to the need of better accuracy and more flexibility on time restrictions for a decision, reliability, efficacy and analysis. In other instances, micro-sized simulations might not be required or possible, in regard to the nature of operations in real time for everyday transport management operations [19] and [20]. In our previous work, we implemented the S-Paramics ITS System controller and demonstrated information of city X to examine the effect on evacuation strategies performance by the intelligent disaster management system. Furthermore, using a software model we enhanced a micro-simulation model, to examine the improvements on the decision for evacuation schemes by the offered system production.

S-Paramics is a micro-simulation model and is satisfactory in imitating traffic on an individual scale on regional freeway and the urban traffic network [21]. Also, the implementation is being further expanded to highlight and shift the traffic conditions during an evacuation. One of the many key advantages with this model is its capability to transfer messages by broadcasting to devices and
information on message signs to vehicles.[22]. Further details about this model can be read in [15]. At predetermined intervals, the S-Paramics ITS system will allow external software’s to communicate with a streaming simulation, to alter parameters within, as well as to extract information from it, using an SNMP interface. The interface for the controller is a Spreadsheet, see Fig. 2. It is the run sheet to record the data which has been written in Visual Basic macro language and is ideal for interfacing to the dynamically linked library that implements the SIAS SNMP interface. In addition to this, the source code is accessible to all, it can be easily modified and is free from the use of complex software tools.

![Spreadsheet interface](image)

Figure 2 The proposed Spreadsheet representing the interface to the model

5. The strategy evaluation
As previously described in Section 4.1, the transportation network of city X consists of nodes, zones and links. Smart future cities have relied on information and communication services provision and this includes the transportation sector. As a result, we are seeking to introduce an emergency system which, as possible as, simulates the transportation evacuation strategies. In this section, we will describe two different scenarios; the first scenario is the city network in normal circumstances. Second scenario where the disaster hits the city in a specific position and causes a huge disruption within the life sectors including the transportation network performance. In addition, the Destination Strategy will take place to manage the scenarios.

5.1. The Disaster Scenario
Consider Fig. 4 which shows different disaster suggestions’ areas. The city can be exposed to a disaster at any moment, whenever and wherever. However, it is not reasonable to forecast the possibility of the disaster occurring, the rapid emergency reactionmirrors the readiness of private and public sectors especially when it comes to providing the correct and effective services [24]. In this city, the transportation trends of the city in regard to an Origin-Destination (O-D) matrix between the city zones will be quantified.
The quantity of journeys displayed in the O-D matrix are calculated in the mid-week period with natural circumstances. Said trips are calculated using the Fratar model (Not purposely differentiating journeys) [25].

The associated possible risks for disaster events can be one of the risks such as: Fire hazards, Failures in technology by reason of shutdown of power plants that feed the area and Terrorist attack. Also, we centre our attention on disaster situation times which may take place at any given time. Traffic circumstances are varied throughout the week. Even though the traffic conditions keep changing depending on the time and day of the disaster event, the methodology used in our simulation model is independent of any specific day or time.

![Transportation network of the X city in normal scenario](image)

**Figure 3** Transportation network of the X city in normal scenario

Typically, the morning peak and the evening peak are of most interest in the traffic network. We assume that the incident takes place during the peak hour/ rush hour, here at 8:30 am. Event as lead to the closure of networks in disaster areas as well as nearby road links. At this stage, to coordinate a city transport, communication with the population to lead them out the city to safety, an emergency response system is needed. Next, we will be discussing and evaluating this emergency response system. In this paper, we assume that a disaster hits area 1, colour in orange, and it has been considered that the situation occurs during the middle of the week, for instance, on Wednesday. Now, we will be able to narrate and evaluate our emergency response system including the Destination Strategy in following sections.
6. Results and Discussion

To increase the possibility of describing the worst-case scenario which can occur to the city, two scenarios for emergency response were considered and the Destination Strategy was applied in both cases and differences in major points was figured out. Primarily, conventional emergency response systems raise awareness among people by broadcasting through radio, telephones or televisions, and by communicating with others in the surrounding area through in-person communication. Secondly, by instinctively gathering information and intelligently processing the data, our VANET based emergency management response system propagates effective strategies and decisions based on the real-time situation, in accordance to the appropriate policies and procedures that are already in place in the system. We evaluate the two systems and compare their performance.

With each strategy/action, the detail of the parameters varies according to the action type, although we need to set in the action row in one or more cells. After the connection is established by the SNMP controller with the objects in the simulation it envisages to collect and manage the data, the simulation then gets instructed to notify the controller. We can send the message to the driver through road variable message signs. These messages could provide a recommendation to be taken by the drivers or data need to be delivered without any followed actions.

Destination strategy is a very important and valuable strategy which can be applied in such scenarios. This strategy directs/redirects vehicles travelling towards a specific area or car park to divert and go towards an alternative. Firstly, we sign the affected roads and zones that are affected by the disaster in order to allocate the damaged area as possible so we can manage the traffic and take a quick snapshot about the majority area that has been affected. Also, note here it is not necessary that the zones near the disaster area are not the only worse area as we notice that any block road can affect severely the rest of the network regardless the spaces between the disaster area and the road as it could depend on the traffic flow or the direction of the traffic stream. The affected roads could be measured by either the number of the accumulated vehicles, by when they start to speed down or even not able to move in some roads or by blocking the entire network. Destination strategy means guide the vehicles either to another safe road not affected by the disaster (alternative roads) or to redirect them to safe areas (evacuation areas).

Some data and details are required to use them in the Spreadsheet. For Destination Strategy, we will give an example of the raw in the Spreadsheet as in Table II:
To interpret Table II components:

- **On time**: start time of the evacuation strategy
- **Off time**: end time of the evacuation strategy
- **Type**: strategy name.
- **P1**: the name of the controller
- **P2**: a car park or waypoint name (the redirection advice). The car park name is preceded by “C” and the waypoint by “W”.
- **P3**: response percentage. In this paper we assume that 100% of drivers are obeying the destination strategy

6.1 *Traditional Response System with the Destination Strategy Scenario*

Typically, disasters tend to force people in the vicinity to move away from the disaster-struck area. In case of the traffic network, a haphazard movement in random directions can be chosen, with the lack of a functional coordination, the roadway zones surrounding the disaster area are barricaded, or in most cases the entire traffic network collapses like a domino. Note in the Fig. 5 that the most roads are blocked (as shown the black coloured roads) or have a very low volume of vehicles of less than 500 per hour (as shown in the red coloured roads). Furthermore, the roads represented by the colour blue, have a volume of 500 to 1000 vehicles per hour and these are the roads far from the disaster area. The volume of vehicles on the roads surrounding the outermost area of the disaster were also recorded to have very high volumes and are represented by the colour green and brown with 1500 vehicles per hour and 1000-1500 vehicles per hour, respectively.

Fig 5 represents the traffic conditions at 9 am, 30 minutes after the disaster has taken place. The opportunity for people to start moving to safe areas, such as evacuation areas surrounding the boundaries of the city, happens in the 30-minute period after an accident. It should be noted, that city X public transportation system only comprises of busses and they are involved only in the case of emergencies, wherever possible.

6.2 *Intelligent Response System with the Destination Strategy Scenario*

An analysis of our advocated VANET based disaster response system will be presented. The catastrophic structed conditions were all the same as in the foregoing section as well as, the role of public transportation in the evacuation process. The ability of the system in terms of how fast having real time information which increases the ability of making the communication easy and applicable to all through advanced technologies and applications such as VANETs, Smartphone and social networks was the only difference in the system. In addition, obtaining the information to treat them and send the reasonable strategy and other related information and managing the transport facilities (for example, the management of traffic signals whenever possible, guiding the traffic navigation systems or other GPS devices by delivering a route map etc). Fig. 6 demonstrates the proposed disaster system after modifying it to reduce the impact of disaster. If both the figures 5 and 6 are closely inspected, more roads in green and fewer roads in black and red can be observed. Moreover, roads with free flow can be observed in a substantial part of the city (shown in the colour green).
Figure 5: The X city network as seen after the city was hit by the disaster, traditional response system with destination strategy.

7. Conclusions and Future Work

The significance of the emergency response systems cannot be emphasized enough due to the recent increase in natural and manmade disasters. The crucial role in disaster response including transportation sector allowing a reduction in economic costs and disruptions and increasing saving lives is a proof of the prominent penetration of ICT in ITS.

In this paper, the effectiveness of RS was analysed with the use of simulation and modelling with the efficacy represented in terms of refined disaster evacuation characteristics. Future work focuses on further investigation and validation of applying our intelligent disaster management system. Also, we are seeking to study and apply additional transportation evacuation strategies.

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