Abstract—The importance of emergency response system has grown significantly in recent times due to the frequent manmade and natural disasters such as September 2001 and Hurricane Sandy 2012. Disaster, manmade and natural, causes great economic and human losses each year throughout the world. Transportation and Telecommunication play a crucial role in disaster response and management. Our previous work was aimed to propose and evaluate a disaster management system based on emerging ICT technologies. In this paper, we especially focus on the factors that increase the potential of our disaster management system performance, the Average Vehicle Occupancy (AVO) factor plays a high important role in the evacuation process and hence in the disaster management system; where a higher level of car occupancy means fewer trips being required for the evacuation process. Hence, the potential of reducing evacuation times by introducing the AVO is presented and evaluated. The impact of a disaster on real city data is demonstrated, and the effectiveness of AVO is evaluated, we report great benefits achieved from the adoption of our proposed system while taking the AVO factor into account, which includes reduced evacuation time, increased number of evacuated vehicle and more balanced traffic flow.

Keywords—Disaster Management System; Intelligent Transportation Systems; VANETs; Cloud Computing; Average Vehicle Occupancy

I. INTRODUCTION

The importance and scope of emergency response systems have grown significantly over the past decades as results of frequent natural and manmade disasters such as September, 2001, London bombing 2005 and Hurricane Sandy 2012. Disasters cause great economic and human losses each year throughout the world. Hurricane Sandy appears to have easily caused an estimated damage of $60 billion (£37 billion) which is greater than any U.S. hurricane except Katrina [1] and [2].

Transportation systems play critical roles in responding to emergencies and minimizing disruptions, human and socioeconomic costs. Transportation is a major public and government concern impacting 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 UK around £20 billion annually [3]. This figure is set to rise to £32 billion by 2025 [4]. In the UK, the Department of Transport has conducted a survey, and they predicted that by 2015 the total traffic on the roads will grow by over 30 per cent compared to the traffic in the year 2000 [5].

Information and Communication Technologies (ICT) are continuing to make profound impacts on the way we live and work, enabling our move towards a Digital Economy (DE), this also include managing disasters and their related problems such as traffic chaos. Previous work [6] proposed a disaster management system and reported the road traffic modeling results, and in [7] a novel message propagation algorithm which contributes in improving the system model was introduced. In this paper, we consider the role of the Average Vehicle Occupancy (AVO) in improving the performance of our emergency disaster management system.

To overcome the delay caused in dispatching disaster related data and information that are considerably effective, we used Cloud Computing approach for this purpose. The motivation and background for a Cloud based distributed control system can be found in some earlier works [8], [9], [10] and [11]. In [8], an architecture for distributed virtualization using the Xen hypervisor was presented; it allows control and management of 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, a Pervasive Cloud was proposed using the WiMAX broadband technology for railway infrastructure [9].

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” [12]. This paper is aiming at presenting 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 cloud vehicular disaster management system [6]. High AVO indicates that more people are ride sharing and hence increase the number of people who are under risk conditions. In addition, it is assumed that AVO should generally be higher in HOV Lanes (High Occupancy Vehicles); where the emergency management system allows the vehicles to use these lanes in special occasions such as disaster situations, than in General Purpose Lanes.

A range of techniques to model evacuation scenarios have been proposed and utilized in [13], [14] and [15]. OmniTRANS is a macroscopic vehicle modeling package, OmniTRANS offers a modern integrated development platform for transport modeling specifically designed to support multiple scenarios, modes and modeling techniques [16] and [17]. The software contains many templates; static assignment, dynamic assignment and transit assignment, that helps the simulator to get different information. Furthermore, the project templates also contain common definitions, useful specifications and lists etc. that are passed from project to project. The user can simply draw the components of the network, then these components are defined, OD matrix for certain time of the day is applied, 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 due to its demo version.

Most of the main functions (except the visualization and network map user interface) in the OmniTRANS package can be carried out by NETRASOFT which has been developed to overcome OmniTRANS limitations [14]. OmniTRANS offers a modern integrated development platform for transport modeling specifically designed to support multiple scenarios, modes and modeling techniques. It is a truly multi-modal multi-temporal system particularly suited to model the interactions of transport modes in an urban context.

In this paper, a tool based on the Lighthill-Whitham-Richards (LWR) model [18]; and an Integrated Multi-Modal Transportation Planning Commercial Package; OmniTRANS [13] is used.

The rest of this paper is organized as follows, Section II reviews related literature to Average Vehicle Occupancy (AVO). Section III overviews the system architecture of our intelligent system proposed in [6], and provides a literature on emergency and disaster management systems. Section IV provides an evaluation of our intelligent disaster management system in terms of the impact of introducing the AVO in the proposed system and finally our paper is concluded in Section V with directions for future work.

II. RELATED WORK

AVO value was assumed between 1 and 3 according to past census and the high vehicle ownership in the households.

Guhas [19] conducted many studies on the evacuation of Virginia Tech Campus. He has 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 modeling has been investigated by Southworth [20]. 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, 1.25 workers per commute vehicle): leaving approximately 0.87 vehicles available, on average, to non-working household members. 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 true cross-product effects of 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 [21].

III. THE DISASTER EMERGENCY RESPONSE SYSTEM

A. System Architecture

The system architecture of the Cloud-enabled vehicular disaster management system, as sometimes we call it emergency response system, was developed and evaluated in [6] and [7]. The system consists of three main layers; the Cloud infrastructure layer provides the base platform and environment for the intelligent emergency response system. The Intelligence Layer provides the necessary computational module and algorithms in order to devise optimum emergency response strategies by processing of the data available through various sources. The System Interface acquires data from various gateways including the Internet, transport infrastructure such as roadside masts, mobile smart phones, social networks etc. Also, vehicles interact with the gateways through car-to-car (C2C) or car-to-infrastructure (C2I) communications. 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. Our intelligent emergency response system provides multiple portals or interfaces for users to communicate 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.

### B. The Intelligence Layer

The Intelligence layer consists of various mathematical modules, algorithms and simulations, both stochastic and deterministic. We have used a range and mix of modeling and simulation technologies including macroscopic and microscopic simulation models; OmniTrans and PARAMICS transport planning software. The data received from various sources go through an assessment layer before it is accepted by the modeling and analysis layer.

The modeling or simulation algorithm is used for a particular activity based on the nature of the activity. 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 demands on 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.

We consider the Lighthill-Whitham-Richards (LWR) model [18], a macroscopic model, to represent the traffic in the city. The LWR model can be used to analyze the behavior of traffic in road sections, and describe the dynamic traffic characteristics such as speed (u), density (ρ), and flow (q). The model is derived from the conservation law (first order hyperbolic scalar partial differential equation) by using the following equation [22] and [23]:

$$\frac{\partial \rho}{\partial t} + \frac{\partial u\rho}{\partial x} = 0$$

Where $\rho$ is the traffic density in vehicle/km, and $u$ is the traffic velocity according to distance $x$ and time $t$. By using Greenshield traffic model [23], the relation between $\rho$ and $u$ could be as follows

$$u(\rho) = \begin{cases} \rho_{\text{max}} \times (1-\rho/\rho_{\text{max}}) & \text{for } \rho < \rho_{\text{max}} \\ \text{constant} & \text{for } \rho = \rho_{\text{max}} \end{cases}$$

Where $u_{\text{max}}$ is the maximum speed, and $\rho_{\text{max}}$ is the maximum density. The fundamental relationship between flow, density, and speed is given by

$$q = \rho u$$

We use flow and volume interchangeably. Having given here the mathematical description of the macroscopic model that we employ, in the next section, we will describe our approach for city evacuation in a disaster emergency situation.

### C. The AlRamadi City and its Transportation Network, Case Study

The Ramadi city (Al Ramadi) is in the west of Iraq and is situated at the intersection of the Euphrates River and Al-warrar Channel. The Habbaniya Lake is located a short distance to the south of the City of Al Ramadi. The present population of the city is estimated to be approximately 230,500 [24].

Figure 1 shows the transportation network map of the Ramadi city, the network consists of zones, nodes, and links. The city is divided into 5 traffic zones; 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 center which attracts high number of trips in the morning peak hour. Also, in this figure, the orange line indicates the railway track.

Figure 1 also shows 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 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. 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, it will be best provided through the international roadway. The area in the east side of the city is mostly agricultural land and is a private property, where the communication infrastructures are poorly provided. The west road leads to a nearby city about 30km away, this city has a good hospital but it can be best reached through the northern international roadway.

![Transport network of the AlRamadi city](image)

Emergency response systems are an extreme example because the availability of real-time data may be greatly limited due to the unavailability of many communication sources during the disaster (e.g. broken communication links). In addition, 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. It is important to note here that we envisage a Cloud infrastructure which is virtualized and flexible to exist, or moved, outside the area affected by the disaster, this is possible considering the capability of Cloud technology.
IV. SYSTEM EVALUATION

The transportation network of the AlRamadi city consisting of zones, nodes, and links has been depicted earlier in Figure 1. We now make use of our earlier discussions in Section III and describe the disaster scenario in Section 0. In Section IV.B, we present and evaluate the AVO model and value. Subsequently, we present analysis of the system and establish its usefulness as a disaster response system in case of considering AVO.

A. The Disaster Scenario

In Table 1, we quantify transportation trends of the AlRamadi 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 natural conditions. These trips are calculated using the Fratar model [25]. Note that the highest rate of trips is toward destination Zone 2 in the city center.

**TABLE 1 AN O-D MATRIX OF THE TRANSPORTATION NETWORK IN RAMADI CITY**

<table>
<thead>
<tr>
<th></th>
<th>zone 1</th>
<th>zone 2</th>
<th>zone 3</th>
<th>zone 4</th>
<th>zone 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>zone 1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>zone 2</td>
<td>82</td>
<td>0</td>
<td>172</td>
<td>935</td>
<td>228</td>
</tr>
<tr>
<td>zone 3</td>
<td>172</td>
<td>2757</td>
<td>0</td>
<td>1171</td>
<td>108</td>
</tr>
<tr>
<td>zone 4</td>
<td>343</td>
<td>10026</td>
<td>381</td>
<td>0</td>
<td>248</td>
</tr>
<tr>
<td>zone 5</td>
<td>272</td>
<td>4835</td>
<td>358</td>
<td>1699</td>
<td>0</td>
</tr>
</tbody>
</table>

In Zone 1 lies a glass factory and beside it is Al-Warrar dam; both of these pose major risks to the city. We consider in this paper 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:

- 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 above listed disaster events is required to handle the emergency situation and saving peoples’ lives. We now focus 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. explosion of hazardous materials in the glass factory.

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 condition in the traffic network is in the morning peak (herein between 7:30 am to 8:30 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 center usually begins after 9:00 am, at this time the peak hour are somehow relieved.

We consider that the incident happens at 9:30 am. The event causes the network to be closed in the Zone 1 and some nearby road links. An emergency response 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. In this case, people will be moved to the two evacuation areas (see Error! Reference source not found.; we have already discussed the justification of the two evacuation areas in Section Error! Reference source not found.).

B. Average Vehicle Occupancy

Vehicle occupancy treatment takes a great part in the evacuation process; the higher number of car occupancy means less number of trips required to the evacuation process, this may make the following benefits:

- Reducing any unnecessary movements of cars
- Increasing vehicle utilization.
- Increasing the transportation supply and enhance the management and coordination of traffic movements.
- Decreasing the conflicts between vehicle movements and reducing the number of the expected traffic accident.

AVO determines the minimum evacuation time for each evacuation area. 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 [26].

\[ T_{\text{min}} = \frac{(\text{Pop/AVO})}{Rc} \quad \ldots \quad (4) \]

Where:

- \( T_{\text{min}} \): Minimum evacuation time, in hours.
- \( \text{Pop} \): Population of evacuation area, in persons.
- \( \text{AVO} \): Average vehicle occupancy, in persons per vehicle.
- \( Rc \): Roadway capacity in vehicles per hour.

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.

The Al-Ramadi city has a population approximately 230000 people, 90% of workers have access to one or more cars; 30% of households have access to one or more cars. The most mode of travel is by using a private car as a driver or a passenger; this will lead to an average 3 people per vehicle as
vehicle occupancy according to the high car ownership in the city households.

Therefore, the number of trips needed is,

\[ 230000 \div 3 = 76667 \text{ trips} \]

The population is to be carried by 76667 vehicle trips on the paths that leading to the evacuation areas. Typically, the government has encouraged the people to use the public transport mode in order to reduce the chaos condition that can be raised in such situations.

In case of this city, and in order to evaluate the AVO contribution, we use the minimum evacuation time Equation (4) which has taken the AVO factor into account and estimate the minimum evacuation time. Here; we apply a range of AVO; 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 2.

C. AVO Contribution in Emergency Response System

In [6], we have evaluated our proposed VANETs and Cloud based disaster response system. In this section, we are going to evaluate our proposed intelligent disaster management system by considering the factor AVO, the results are shown in Table 2.

TABLE 1 MINIMUM EVACUATION TIME WHEN CONSIDERING AVO

<table>
<thead>
<tr>
<th>Average Vehicle Occupancy, AVO</th>
<th>Minor Road</th>
<th>Major Road</th>
</tr>
</thead>
<tbody>
<tr>
<td>C* = 900v/h</td>
<td>1 Lane</td>
<td>1 Lane</td>
</tr>
<tr>
<td>1</td>
<td>255.555</td>
<td>255.555</td>
</tr>
<tr>
<td>1.5</td>
<td>170.37</td>
<td>127.78</td>
</tr>
<tr>
<td>2</td>
<td>127.777</td>
<td>63.888</td>
</tr>
<tr>
<td>2.5</td>
<td>102.222</td>
<td>51.111</td>
</tr>
<tr>
<td>3</td>
<td>85.185</td>
<td>42.592</td>
</tr>
</tbody>
</table>

C* = Capacity

The AVO impact on our system is shown in Figure 1 and TABLE 1. It shows the required AVO value to get the minimum evacuation time for a particular road layout when the disaster management system triggers of and let the evacuees to use their own vehicles; if applicable.

No one can underestimate the importance of this factor in disaster situation to help people who have no access to the assembly point or the assembly point is too far from where they present in 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. The importance of collecting 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 (4), and assuming different AVO to different road layout. The result shows that we need less time to evacuate the vehicles in case of applying higher AVO on same capacity of the roads.

![Figure 1 Estimation minimum evacuation time vs AVO for different lanes capacity](image)

The trip generation models have a great contribution on 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 disaster the trip generation models may depend on type of population in 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. A time dependent traffic evacuation model was proposed [6], this model depends on the bases of LWR model and implemented by several models like the models used by OmniTRANS software as a tool. This traffic model include estimating the new traffic demand for the evacuation from existing traffic zones to a new traffic zone at the evacuation safe place, the AVO majorly affects the new traffic demand, and then the new demand is generated to the supplied transportation network to reach the safe place, in this case, the capacity of the links and joints have a dominate effect on the strategy. 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.
V. CONCLUSIONS

The importance of emergency response systems cannot be overemphasized due to the many manmade and natural disasters in the recent years. A greater penetration of ICT in ITS will play a critical role in disaster response and transportation management in order to minimize human casualties, economic costs and disruptions. In this paper, we introduced and evaluated the AVO contribution to evacuation time. The system architecture and components were described. We have also provided a fairly detailed introduction to the method and factors that we have considered in modeling disaster and evacuation scenarios and analyzed our proposed system. Results have shown that AVO contributes effectively in evacuation plans that are in place; this has indicated that neighborhood 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. The analyses which carried out over a chosen city and considering given scenario will feed into establishing suitable methodology and tools which are capable of bringing innovations in the disaster management area as well as in the broader transportation area.

REFERENCES


