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Influences of Multi-Evacuation Strategies on Smart Networks

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Abstract

Catastrophes have increased over recent years, highlighting the need for effective disaster management systems. The largest earthquake to hit Turkey since 1939 caused damage to roughly 350,000 km² and affected 16% of Turkey's population. United Nations development experts estimate 1.5 million people were left homeless. The confirmed death toll was 53,537, with damage estimates at US$148.8 billion. Roads and communication disruptions hampered the pre-planned Disaster and Emergency Management system. Previous assessment of intelligent emergency response systems emphasizes the need for transportation networks in large-scale catastrophes. This study shows how the Intelligent Transportation System could be utilized in conjunction with emergency evacuation strategies in various situations. Meanwhile, to assess the evacuation strategies' performance, the Intelligence Disaster Management System uses different technologies, like mobiles, social media, and vehicle devices, etc., in place of communication infrastructure and platforms. These strategies include demand, destination, and speed strategy. This research aims to model system performance and the aftermath of a disaster in a realistic urban transport city. Later, findings are compared with a control group that had a previous disaster control system. The combination of strategies compared to a singular strategy showed an increase of flow volume of 1.92 times greater.

Keywords: Demand Strategy, Destination Strategy, Intelligent Disaster Management System, Speed Strategy, Vehicular Ad hoc Networks

1. Introduction

Disasters caused by natural or human-made resources, such as the heat waves that hit various European nations in 2022 and the flood that swept through various South Asian countries in 2020, have resulted in a major growth in emergency response systems over the past decade. The explosion of incorrectly stored nitrate at the Port of Beirut in 2020 is an example of a chemical disaster [1]. Due to the randomness of their scale, timing, and destructive potential, disasters have always posed a significant threat to human life and civilization. Every year, disasters cause significant damage and casualties all around the world. During the heat of 2022, portions of Europe were hit by a series of heat waves that led to mass evacuations and several fatalities. The most common were continental-scale droughts [2]. Road accidents remain one of the leading causes of death globally. According to the World Health Organization (WHO), approximately 1.35 million people die each year as a result of road traffic collisions [3]. Many nations, including the United States and Europe, have responded to this with new programs and laws [4]. Disasters widely damage distribution lines and transport roads, ultimately leading to congestion, blockage, and eventually interruption [5].

Crucial functions for ICT (Information and Communication Technologies) include early detection of crises, rapid response, and mitigation of disruption and its human, social, and economic effects. Prior work by Alazawi et al. illustrates the changes brought about by ICT [6],[7].

In addition, these technologies have played an increasingly central role in ICT infrastructure upgrades throughout the years. One of the most significant public and governmental concerns, transportation policy, impacts every facet of modern life. New technology, such as various sensors, in-vehicle gadgets, and social networks, has aided in the evolution of transportation for people and goods. Other novel technologies also open up new avenues for transport. Large amounts of high-quality, actionable data are being produced by vast networks of vehicles and sensors, making now the perfect moment to regulate and monitor transportation systems in real time and with fine-grained precision.

This paper illustrates how to profit from the rapid technology of digital communication and information systems. Implementing a series of evacuation tactics known as the demand strategy, the destination strategy, and the speed strategy also suggests and analyzes the effectiveness of an urban traffic network. It evaluates the current network traffic condition against the baseline scenario that does not include the strategy. The Intelligent Disaster Management System proposed previously will measure the strategy’s effectiveness. The present system simulates the results of a disaster striking an actual city. Specifically, two urban settings were simulated. Traditional methods of disaster management come first, while using an intelligent Vehicle-Based Disaster Management System comes second. The performance of this system is represented by traffic flow, optimal distribution of transportation means and the maximum number of vehicles that may be moved from one location to another safely. These measures are starkly different across the two scenarios:

Transportation evacuation tactics are explained in Sections II and III of the present article. They include an overview of various technology applications that have been incorporated into the proposed system. Section IV of this work evaluates the current system and the strategy’s success. Section V discusses the study’s implications and suggests more research.

A strategy is defined as a specific skill that allows a system to adapt to certain aspects in unpredictable circumstances.

The gap was utilized to synergistically use speed, destination, and demand strategies to improve flow volume in a capacity that provides greater efficacy than the sum of its parts. A range of strategies has been suggested in order to overcome the challenges and prevent losses.

The combination of destination, speed, and demand strategies has yet to be researched; we aim to cover this specific mixture in the paper as they cover different aspects in ITS (Intelligent Transport System). This is significant as it could create an enhanced ITS–based evacuation that is more effective.

2. Literature Review

2.1 The State of the Art

The transportation industry uses a wide variety of technology in the form of vehicles and infrastructure. Our networks rely heavily on the cutting-edge technology of ITS permissions, vehicular communication, V2V, and V2I technologies. It is a relatively new study area in Mobile Ad Hoc Networks. It is designed to improve traffic flow and vehicle safety by allowing vehicles to communicate with one another through a wireless connection. The network facilitates the exchange of information and safety-related data. Each vehicle shares data and works together to maximize information and efficiency [8].

This technology’s core principle may be summed up as follows: nodes communicate with one another and relay information via mobile messages and static masts installed along the vehicle’s path. Road traffic information has previously only been obtained through cameras, inductive loops, roadside sensors, and surveys. Modern technologies offer new opportunities for gathering information and rapidly distributing data collected in real time. With the information that communication nodes may share their data, a complete picture of the road condition can be compiled in real-time [9]. These modern technologies, which have opened the door to a wide variety of new uses and applications that improve transportation safety and efficiency, are the primary motivators for this driver. Finally, a wide range of ITS stakeholders, including governments, telecom providers, and automakers, are working together to bring about an ITS based on modern technologies.

2.2 Intelligent Transportation Systems

Entertainment, desire-assurance, technological progress, flexibility, and transport are all basic instinctive needs. Meeting such requirements opens the road for the widespread adoption of Intelligent Transport Systems (ITS).

“Emergency evacuation” is the process of getting people out of a dangerous area before a disaster so that there are fewer deaths and less damage to property. [10].

During emergencies, communications were crucial for monitoring and directing evacuation efforts. Whenever a natural or manmade disaster strikes, residents of the region usually have little choice but to adhere to the instructions issued by local emergency agencies. The pathways begin to shift and carry the afflicted to a more secure location [11]. Specifically, a three-tiered, intelligent emergency system is created. The IER is supported by and runs on a cloud infrastructure layer. The computational and algorithm modeling provided by the intelligence layer is needed to assess data from various sources and improve emergency response plans.

The system’s user interface pulls data from various sources, including mobile devices, servers, social media sites, and roadside masts. Fig. 1 depicts two possible vehicles of vehicle-to-gateway interaction: car-to-infrastructure (C2I) and car-to-car (C2C). For instance, using the internet to communicate with a gateway is viable if such communication is available. Vehicles and road towers may be able to communicate with one another through broadcast, point-to-point, and multi-hop communications.

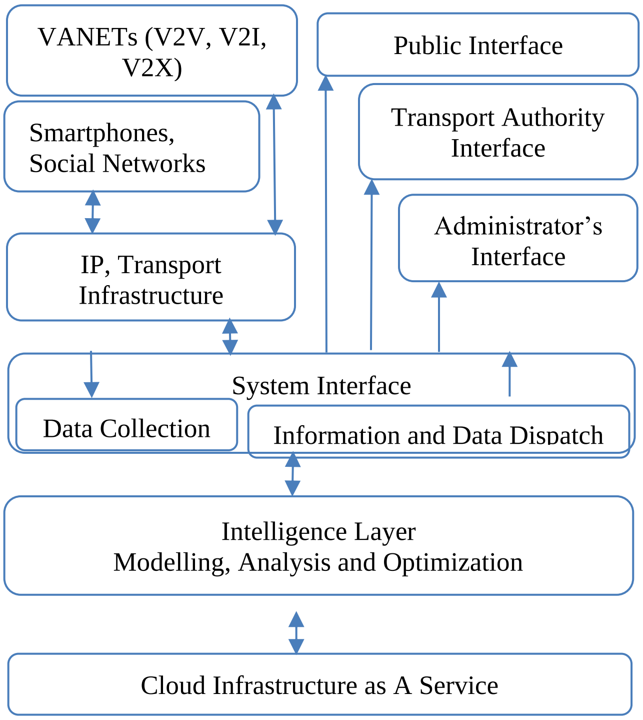

Figure 1. Emergency-call system structure.

3. Methodology

The importance of emergency evacuation strategies has grown tremendously, particularly after major disasters around the world. These strategies can be implemented to enhance the transport network performance, hence reducing the chaos and ordinating network users and avoiding the community life losses. Therefore, the stakeholders provide the sustainable operations of transportation strategies during emergencies. Below, Fig. 2, is a flowchart that gives a simple understanding of how the procedure of controlling the situation after a disaster.

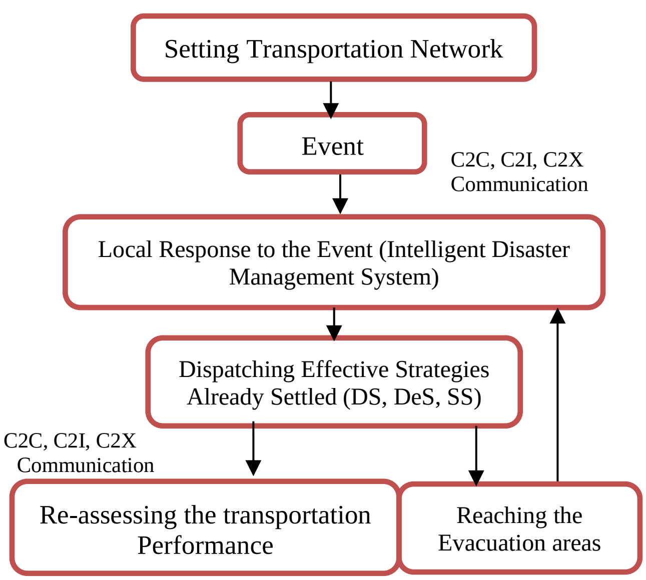

Figure 2. Emergency evacuation strategies implementation

The kind of disaster, location, time of day, and driver behavior may significantly impact evacuation strategies. Consequences may be seen differently depending on several situations; hence, following the issued regulations carefully is crucial to achieving the best possible evacuation outcome. Some drivers in such situations rely on their long-term memory networks' (myopia) estimates of future traffic conditions, remaining trip time, other routes, and traffic at their destination. How quickly pedestrians and motorists respond to the situation is critical. Prior and present publications assume that virtual cloud infrastructure will make several technological resources and advanced technologies readily accessible. Improved evacuation times may be achieved by increasing the speed with which the control management unit and the driver exchange emergency alerts [7]. Despite numerous approaches for assessing evacuee behavior, more extensive research is needed in order to determine the right circumstances for when a certain methodology is employed [12].

Among the many necessary steps to take during a disaster, evacuation is a critical one. Many different types of evacuation plans, including sudden, voluntary, forced, directed, and notice vs. no-notice evacuation, have been tried and experimented with [13]. Several strategies may be used, evaluated independently, and tested simultaneously. Alazawi et al. [6], [7], Mehmood and Nekovee [14], and others have examined the efficacy of three distinct evacuation strategies in the past.

3.1 City's Transportation Networks

The area's urban metropolis may be found in the country's middle. The population was last based on 2001. However, in 2012, the Office of National Statistics placed it at 170,000. Several evacuation experiments that have been organized in this city are covered throughout this study. We agreed with the city council that it would be inappropriate to use the city's name in this context. The city's transportation network and other critical networks (including nodes, zones, and linkages) are shown in Fig. 3. The city map displays the city's 26 distinct zones. Evacuation Areas 1, 2, and 3 are shown in Fig. 3. They recommend providing a suitable and safe location for the population if a catastrophic event forces an evacuation of the city. These areas have been selected as evacuation zones for several reasons. The location was chosen because of its proximity to a highway. It connects the local roads to the roads leading into the next city. Additionally, several locations inside the city are mostly residential. Likewise, there are other junctions we do not go near since they can be in desert or agricultural territory, leaving those needing medical attention without adequate access to emergency facilities.

3.2 Transportation Evacuation Strategies

In this study, the simultaneous implementation of the three applicable strategies—Destination strategy (DS), Speed strategy (SS), and Demand strategy (DeS)—in the evacuation strategies will be studied. Due to the sensitivity of data regarding disaster effects on infrastructure, no public information exists to validate the data (include citation); however, validation can be proved using datasets collected before and after the implementation of the strategy. In normal scenarios and many other traffic network minor problems, it has been noted that validation level cannot be underestimated, it is concluded that necessary validation is out of reach for evacuation researchers [15]. The situation and any necessary evacuation measures are presumed to be within the complete and total control of the strategies.

The present study develops a mobile-based disaster management system based on three combined strategies. Following predefined rules and procedures, it automatically gathers information, analyzes it intelligently, and then generates and disseminates effective strategies and decisions based on the current critical scenario. Three strategies were used together in this piece of art. Specifically, they were the DeS (demand strategy), SS (speed strategy), and DS (destination strategy). The project-wide success of the strategy's implementation is then assessed. The next step is to either continue with the current procedures or evaluate whether a strategy change is necessary. In other words, the suggested system's performance is contrasted to that of the traditional model, and our suggested system after adopting the evacuation strategies. The system analyzes traffic conditions and evaluates the management of the network's disaster measures. The system will obtain the information from different resources.

3.2.1 Demand Evacuation

In the transportation sector, it is difficult to allocate the number of vehicles that use a particular route, as it is common for drivers to change their mode/route or even destination for any reason. Thus, research should be considered to value the significant conditions, such as the area (commercial or residential), zones (city center), and routes (highway or arterial). With these conditions and more, most routes can have a high level of practice prediction. Transportation demand can be defined as the traffic and transportation system in a reciprocity relationship with society and economic development [16].

3.2.2 Destination Strategy

The evacuation scenario may be assumed and analyzed whenever warnings are sent for catastrophes, dangerous conditions, or heavy traffic. The time required to remove the same number of persons and vehicles from the impacted or risky area and/or the encircling area is a good indicator of the effectiveness of the evacuation strategy. The number of vehicles that may be prevented from reaching the disaster zone is likewise determined by this factor. It is possible to monitor the driver's actions and weigh certain crucial choices to save costs with this strategy.

3.2.3 Speed Strategy

Important factors include travel time, volume, and speed under varying traffic conditions. One of the primary goals of transportation management is the elimination of incidents that cause traffic backups on freeways. Traffic might be directed in two opposite directions, making the evacuation speed strategy crucial. One is to slow down so as not to enter the infected zone, and the other is to speed up to flee the zone as soon as possible.

3.3 Simulation Model

Management of disasters and their evacuation can be strengthened by utilizing developed, effective simulation models [17]. It is possible to provide simulation models at the micro and macro levels to explain the transportation issues. Micro-sized simulations may be impossible in some situations. For example, micro-scale traffic modeling is cost-effective and obligatory for developing new transport regulations and models. This is because there is a growing need for higher levels of precision, more leeway in how quickly a decision must be made, better reliability, efficiency, and more thorough analysis. The nature of real-time operations makes macro-simulation the best option for routine transport management tasks.

The S-Paramics ITS System Controller was utilized in our prior research to display city X data and examine how the intelligent disaster management system's efficacy influenced evacuation plan implementation. Additionally, to test the improvements in evacuation scheme decision-making brought about by the proposed system production, we supplemented a microsimulation model with a software model [18], [19]. The S-Paramics micro-simulation model successfully replicates individual-level traffic on the urban and regional freeway networks. The implementation is also improved to highlight and adjust traffic situations throughout an evacuation. Transferring messages via broadcasting them to machines and data on message signs to vehicles are two of the numerous benefits of this model [20].

The S-Paramics ITS system provides an SNMP, which 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. 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 to enable using of interface by employing Visual Basic (VB) [20]. The underlying communications mechanism is SNMP. The "controller" starts the simulation and establishes a connection to it. Once a connection is established, the controller creates the links to the objects in the simulation it intends to manage. In this case these are message passing ITS controllers, traffic signals and smart technologies which have been employed in the proposed disaster management system.

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. The SNMP interfaces for other programs to connect with a streaming simulation at regular intervals, allowing them to adjust to the simulation and pull-out relevant data. A spreadsheet serves as the controller's user interface. A datasheet in Visual Basic's macro language stores all of the information. It is a great connector between the program and the DLL (dynamic link library) that supplies the SIAS SNMP interface. Not only that, but everyone can look at the source code. It is simple to edit and does not need any special programs.

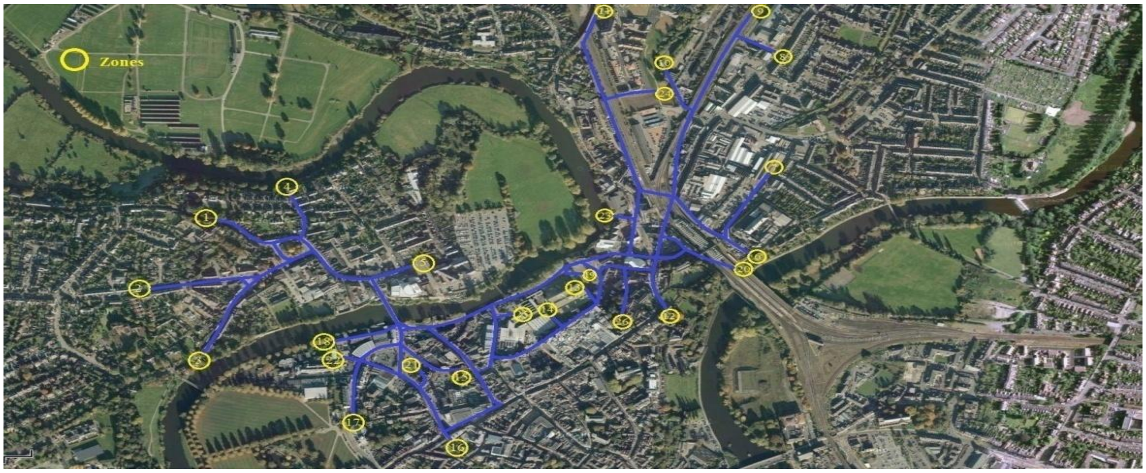

Figure 3. The X city's public transportation network, normal situation

3.4 Disaster Scenario

Through dialogue with the authorities of the city, we reached a compromise that the test can be carried out under the terms of redacting the city name due to concerns on the impact of a study on the perception of the city.

Meanwhile, the reproducibility of the synergistic strategy was assessed by repetition throughout different days, different time periods, different intersections; it is important to note that the city layout, climate and industry are comparable with many cities across the world. Across many intersections, at peak hours, on different days, one road of each intersection was blocked independently, and the effect on the traffic flow of the network was assessed. This was repeated for all other roads of the intersection, and the effect was subsequently measured. Strategies were then applied to the road with the greatest consequence on traffic flow, which was thus selected at each intersection, as it constitutes the primary bottleneck during a disaster.

Research and studies on urban network traffic often focus on the morning and evening rush hours. The event probably happened at about 8:30 am in the morning rush. It causes disaster-stricken communities and the surrounding areas to lose access to networks and transportation linkages. It is now necessary for an emergency response system to integrate city transportation and interact with the populace to direct people away from the city to safety. The next step is to analyze and assess this emergency response system. For the sake of this study, let's say a disaster does occur in Area 1.

The middle of the week, say Tuesday, has been proposed as the most likely situation for this to occur. Our emergency response system, which incorporates Demand, Speed, and Destination Strategies, will be described and evaluated in the subsequent sections. Several disaster-suggesting zones are shown in Fig. 4. The city might be vulnerable to a disaster anytime and everywhere. The speedy emergency reaction mirrors the preparedness of the public and private areas, particularly when delivering proper and effective service. An OD (origin-destination) matrix will measure transportation patterns within the city's zones.

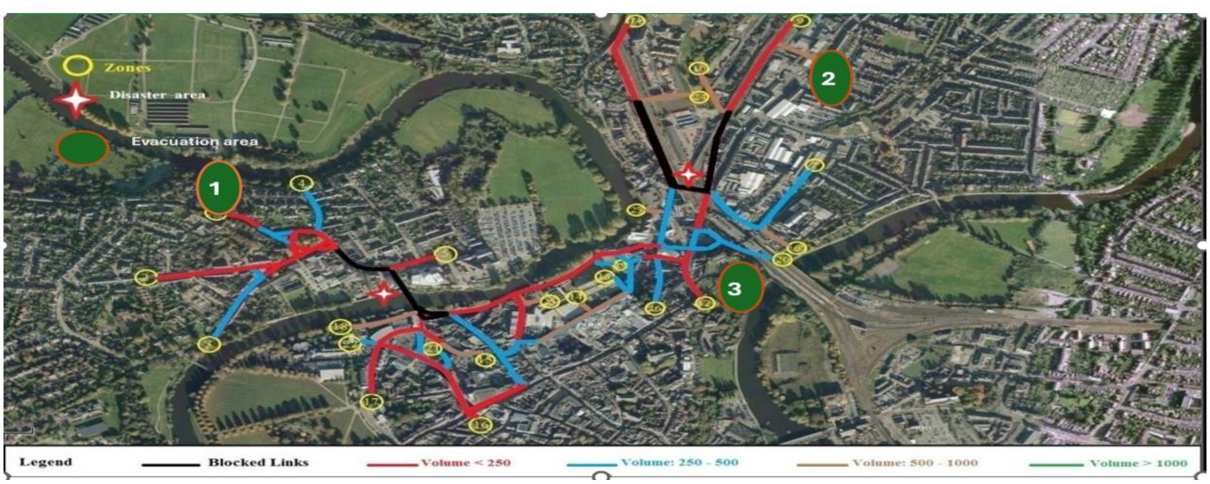

Figure 4. An illustration of various disaster locations in the city and the possibility of having disasters in these locations

4. Results and Discussion

Two emergency response scenarios were explored, the three evacuation strategies were performed in both circumstances, and the critical distinctions between the two were worked out to raise the likelihood of expressing the worst-case situation that may occur to the city. Traditional emergency alert systems notify people in the affected area by disseminating telephones via radio, public, or television and making direct human contact. Assigning paths for driver movement is limiting; traffic jams could alter the course taken. The model showed flexibility, allowing people to switch destinations or take alternative paths. Moreover, abiding to speed limitations will allow the driver and network users to keep clear of the dangerous area as much as possible. Additionally, the system will take into account the network capacity in order to evade road conflicts. In an emergency, our advanced technologies-based response system propagates vital information without human management while using the appropriate rules and procedures already established in the system, it intelligently analyzes the data to transmit useful decisions and strategies based on the present situation. Both methods' efficacies are analyzed and contrasted.

The parameters for each strategy/action differ in fine detail depending on the kind of action taken, but all need a setting in the action row in one or more cells. The SNMP controller plans to gather and manage data when it has connected to the objects in the simulation. The simulation then notifies the controller. The message may be sent to the driver using road-changeable message signs. These alerts may instruct drivers to take action or convey the need to send data. Certain information and data are necessary for usage in the Spreadsheet. Table 1 illustrates the raw data included in the spreadsheet used to create the Destination Strategy. Table 2 illustrates raw data in the Spreadsheet for Speed Strategy.

Table 3 is an instance of raw data in the Spreadsheet for Demand Strategy.

Table 1. Destination strategy sheet for an SNMP controller

Ref.	On time	Off time	Type	P1	P2	P3
	Evacuation strategy beginning time	Evacuation strategy ending time	Strategy name	Controller's name	a waypoint name or car park *	%response **
1	8:45	10:00	Dest.	Con.1	Southway	6

* The waypoint is preceded by "W" and the car park by "C."

**Every single driver is presumed to be sticking to the destination strategy.

Table 2. Example of speed strategy sheet with different conditions.

Speed limit, mph			
Increase d	**Decreased**	**Strategy starting**	**%Driver responds**
40	5	08:45	25
50	10	09:00	50
60		09:15	75
70		9:30	100
70		09:45	100

Table 3. Input data example for a demand strategy worksheet.

Demand strategies						
Ref.	**Starting time of evacuation strategy**	**Ending time of evacuation strategy**	**Strategy**	**Matrix**	**From zone**	**To zone**
1	08:30	09:00	Demand	1	1	5
2	08:30	09:30	Demand	1	2	6
3	09:00	10:00	Demand	1	9	20
4	09:30	10:00	Demand	1	16	21

4.1 Traditional Response System

Most individuals in the immediate aftermath of a disaster will evacuate to safer locations. Random behavior and unexpected course corrections are common in traffic network issues. A few of them wait until they get word from higher-ups before continuing. Due to the incident's potential to spread like a shockwave over the whole traffic network, the roadway segments around a disaster area are restricted or partially closed without good coordination.

Almost all of the roads shown in Fig. 5 are either closed (indicated by the absence of black roads) or have extremely low volume (> 250 vehicles/hour, as demonstrated by the presence of red roads). In addition, few roads beyond the disaster area have traffic volumes between 250 and 500 vehicles/hour (blue roads). Near the crisis's epicenter, disaster volumes average less than 500 (brown) and more than 1000 (red) vehicles per hour, but on the roads of the affected area, they are much higher (green).

The traffic situation shown in Fig. 5's city network and discussed above is a snapshot obtained at 9 am or 30 minutes after the disaster happened. People can begin moving toward and arriving at safe locations (such as evacuation sites, if necessary) outside the city limits in the first 30 minutes after the catastrophe. It is crucial to note that buses are the only mode of public transportation in X city. In an emergency, public vehicles will be used wherever feasible.

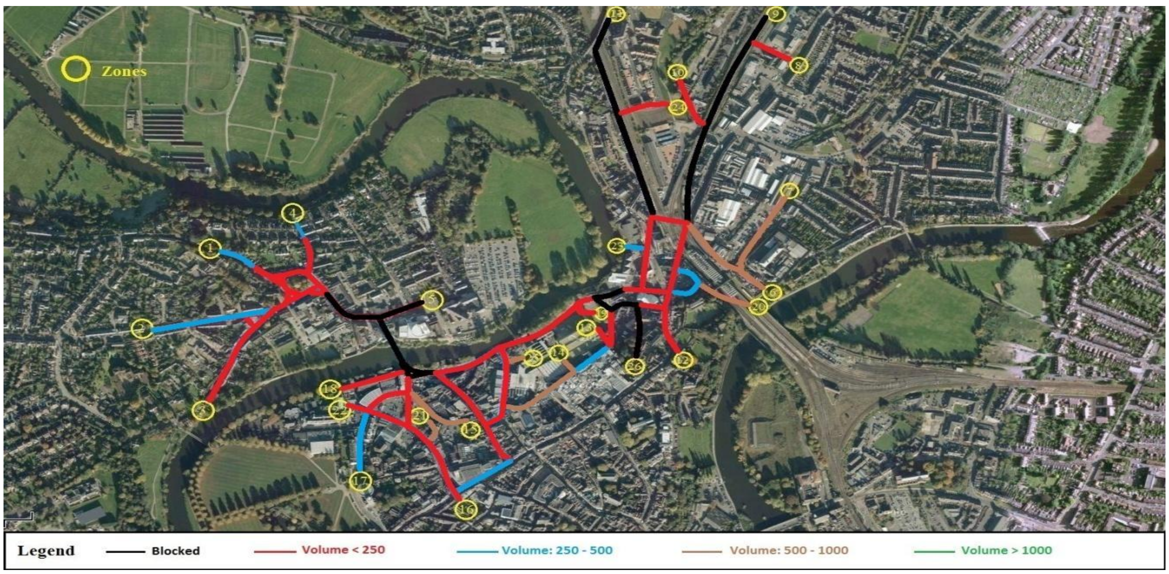

Figure 5. X city network after the disaster, applying the traditional response system (using old communication technologies) from 9-10 am, following the disaster at 8:30 am

4.2 Intelligent Response System

In this section, the suggested intelligent disaster response system is implemented. The conditions of the disaster case, especially the function of public transportation in the evacuation, remain unchanged from the preceding section.

Whether or not the system can deliver real-time data that enables communication via cutting-edge technologies and programs like smartphones and social networks is essential. Additionally, collect the data necessary to treat patients, disseminate valuable strategies and information, and communicate the transport network (controlling traffic lights and providing a route map to GPS traffic systems and other GPS-enabled devices). The suggested disaster management system is seen in action in Fig. 6, where it is utilized to mitigate the catastrophe's consequences. When comparing Figs. 4 and 5, there are several variations; black roads decreased from 9 to 3, red roads decreased from 18 to 8, with high volume roads such as brown and green, totaling 10 compared to the previous 4 in Fig. 5. The total vehicle throughput increased roughly 1.92x from roughly 7875 to 15125 between 9-10am.

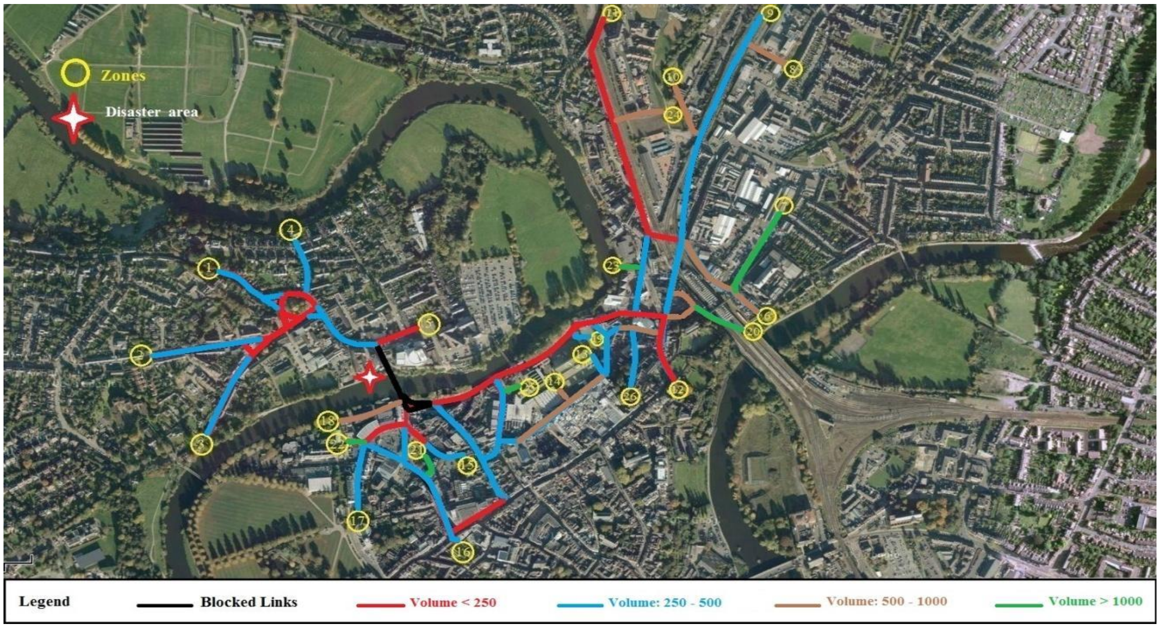

Figure 6 Intelligent response system with Destination, Speed, and Demand Strategies for the X city network from 9-10am, following the disaster at 8:30 am

5. Conclusions

More widespread information and disruption technologies (ICTs) in ITS are needed for disaster response and transportation management to reduce fatalities, economic costs, and penetration disruptions. The penetration of ICT in ITS will play a critical role in disaster response; mobile technologies will play a great role in increasing the safety and mobility of transportation networks. Also, a great advantage of vehicle-to-vehicle communication has been exploited and will increase the speed of the internet for future improvements.

This research employed a tool to compare the efficacy of three evacuation plans based on their relative priorities: speed, demand, and destination. The tool presupposes a dynamic decision-support evacuation scenario. Significant enhancements are accomplished by using the dynamic disaster system and evacuation strategies. The micro-simulation model used by the S-Paramics ITS system was used to assess the system in terms of its enhanced disaster evacuation features. The findings show a significant increase in the number of lives saved using these strategies. An increase in vehicles rescued is also seen in the data. As further research is done, alternative disaster evacuation strategies will be analyzed and validated.

Also, future work will focus on further analysis and validation of the disaster management system, and on broadening the scope of this work to real-time operational and strategic management of transport infrastructure. More real city data will be analysed to examine our strategies on different urban and suburban traffic networks.

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Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Author Contribution Statement

Zubaida Alazawi, Khalid Chaloob and Laith Farhan Jar proposed the research problem.

Zubaida Alazawi and Omar Alani developed the theory and performed the computations.

Zubaida Alazawi, Khalid Chaloob, and Omar Alani verified the analytical methods and supervised the findings of this work.

All authors discussed the results and contributed to the final manuscript.

Data Availability

The data supporting the findings of this study are available from the author upon reasonable request.

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