Developing Sustainable Disaster Transportation Network on Real-Time

Alireza Moghayedi
Research and Technical Studies Department, Ministry of Road & Urban Development, Mashhad, Iran
Email: akm.moghayedi@gmail.com

Helen D. Dillena
National Commission on Muslim Filipinos, Quezon City, Philippines
Email: helendillena@yahoo.com

***Abstract*—This study seeks to develop sustainable transportation network on real-time by providing a capability to dynamically route network under disaster situation. To be responsive to the actual disaster conditions, unfolding the real-time in the transportation network both in terms of the evolving traffic patterns and the availability of road infrastructure in the aftermath of disaster identifies the best possible independent evacuation routes from a potential disaster area to different shelters or facilities. The study also provides iteratively a Heuristic Method to define the two independent paths from the disaster area to each obliging shelters for traffic flow allocation in disaster network by considering both the travelling time and the capacity of the transportation network as parameter for network/data analysis. Routes to different shelters cannot present intersection points either in order to allow continuous traffic flow and to reduce potential accidents.**

***Index Term*—bottleneck, capacity, disaster, real-time, transportation network, travel time**

I. Introduction

Disaster is an event or incident that causes severe damage but can be handled by emergency responders with mutual aid.Emergency Response refers to organized activities to address problems created by unusual events which cause concentrated damages and risks. During disasters and emergencies, the tightness in time, the pressures in decision-making, and also the uncertainties, are so high.

At these complex situations, the disaster management approach is necessary to continuously integrate the multi-sector and multi-disciplinary process of planning and implementation of measures aimed at prevention, mitigation, preparedness, response and recovery in disasters to ensure that the right and necessary measures are prepared and taken in the management incidents under the three different phases of disaster conditions *(Pre-Disaster, During-Disaster and Post-Disaster).*

In addition, transport during disasters can be considered both as requirement of the people to sustain mobility and to fulfill other support functions of disaster management. One of the perspectives of the transport system is focus on the transport functions which aims to provide the mobility and the accessibility to the people. Another perspective of the transport system is the performance of transport system for supporting other systems or system functions for example security, environment or economy functions including disaster management functions during disasters. Thus, transport system supports the activities of other systems or system functions as well as being itself a source of negative impacts on environment, safety and economy.

Lastly, to manage such disaster/emergencies more effectively the design and analysis of disaster transportation network will be discussed to address the real-time operational needs in the context of the sustainable transportation network response problem by providing a capability to dynamically route vehicles under disaster, thereby being responsive to the actual conditions unfolding in real-time in the traffic network, both in terms of the evolving traffic patterns *(demand-side)* and the available road infrastructure in the aftermath of the disaster *(supply-side)*. This method allows the identification of the best possible independent evacuation routes from a potential disaster area to different shelters or facilities [1].

II. Disaster Transportation Framework

The transportation issues under the three phases of disaster which all have major traffic management problems in terms of evacuation, emergency operations, prioritization of recovery operations and post-disaster commuter traffic management [2].

As shown in Fig. 1, several issues enumerated in Pre-Disaster, During-Disaster and Post-Disaster conditions that should be discussed meticulously to minimize the impact and to lessen the risks of disaster on the community/country by designing and analyzing the best possible disaster transportation routes to ensure the safe, quick and efficient transportation of people (evacuees, volunteers, medical staffs and etc.) and goods (medical materials, foods, and etc.) on the transport system from the disaster area to each destination points.

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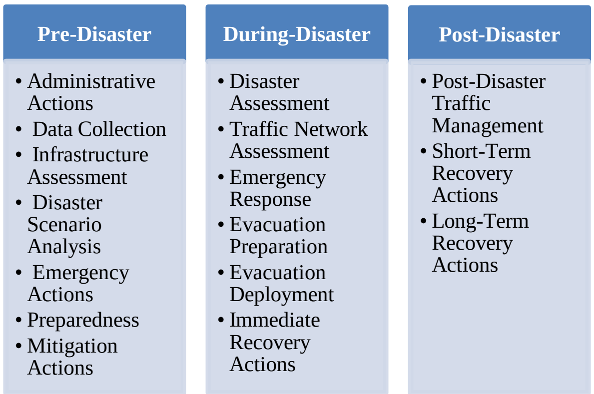

Figure 1. Transportation issues under disaster conditions

Pre-Disaster: The traffic management framework, disaster risk management, evacuation planning and transportation networks are an integral component of disaster management as preparation prior to disaster.

During-Disaster: Transport during disaster/just after disaster required the search and rescue operation; delivery of emergency supplies and services, etc.; carry of victims from collapsed structure to local hospital and shelters. The emergency transportation and the public transport services are component of all emergency preparedness efforts

Post-Disaster: It is important to include disaster response as part of all transportation planning to local, regional, national transit and etc. to consider the widest possible range of possible disaster and stresses on transport system and evaluate the wide range of possible solutions; to develop a multi-modal transportation system that can provide a variety of mobility options; to create transportation system networks that provide multiple links to each destination.

III. Disaster Transportation Network

The major problem in disaster transport operations is the exit routes of disaster area which are often limited in number and insufficient in capacity to handle the traffic surge during a large-scale emergency transport. So, the capacity of transportation networks generally cannot satisfy the intense demand for disaster transportation.

However, to improve the planning and operational aspects of the transportation disaster process; and to maximize the utility of the existing transportation network of the potential disaster area the main roads must be clearly incorporated beyond the definition of the source and destination nodes. The origin of the flow can be only one and, if there is more than one place, it is necessary to create a fictitious origin that will be linked to the several sources. The proposed method allows a previous analysis of several scenarios including the total flow of vehicles in the disaster transportation, alteration in the orientation of the roads and the location of the shelter/places for the population. It can also be associated to a simulation process [3].

Therefore, to manage the traffic surge particularly during large-scale disaster the flowchart illustrated below is vital to analytically design, analyzes, evaluate and optimize the disaster transportation network to provide the fastest/shortest/safest routes and to unruffled the traffic surge in the designated area.

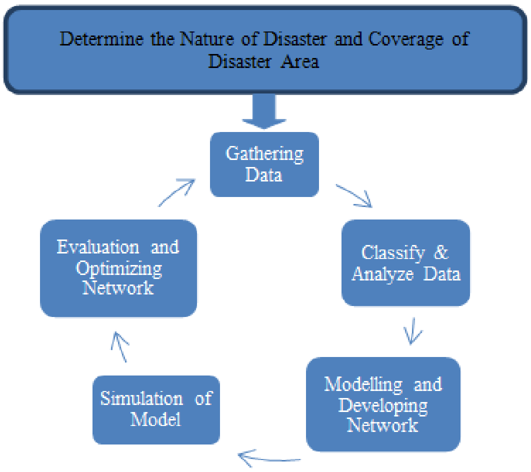

Figure 2. Optimizedisaster transportation network

For instance based in Fig. 2, in disaster coordination meeting the nature of disaster and its coverage area should be determined. All necessary data for developing a disaster network model should be gathered, classified and analyzed on real-time.

Instantaneously, developed model will simulate and evaluate. Developed transportation network model will be optimized in proportion to output of simulation of model.

To sustain the transportation network model in optimize level, real-time traffic data and condition will gather from ITS devices and insert to the model.

The disaster network model will modify and revise to the real-time traffic data and network condition to sustain model on optimize level.

IV. Modelling and Developing Disaster

This study applies iteratively a *Heuristic Model* to define two independent paths from the disaster area to each shelter for vehicle flow allocation in disaster transportation network, considering both travelling time and capacity of the transportation network as parameter for network analysis. Routes to different shelters cannot present intersection points either in order to allow continuous traffic flow and reduce potential accidents.

Techniques and models have been developed to simulate the transportation network on affected area with the main objective of identifying the problems that can happen in the disaster transportation network. These problems can be vehicular congestion and accidents that can contribute to increase the travel time and the number of injuries. However, conventional methods and heuristics for defining disaster routes generally are based mainly on geographic proximity and seek for the shortest travelling time. Such techniques do not guarantee that the capacity of the routes will satisfy the intense demand for transportation during disaster, and neither that the resulting routes will not present coincident intersection points, which could be eventual bottlenecks susceptible to potential accidents [4].

In this paper, it introduces a method for defining two independent paths from the disaster area to each destination points for vehicle flow allocation in disaster network planning, considering both travelling time and capacity of the transportation network as parameters for analysis. This type of paths has no intersection points. Besides, routes to different destinations points cannot have intersection points as well, so its use minimizes the problem of accidents and permits a continuous traffic flow.

The application of this method allows the identification of the best possible independent routes from a disaster area to different destinations which previously defined. The method is eliminating of jointed paths with intersection points among the possible routes. However, in cases which a set of routes without intersection points is unfeasible, the method provides previous knowledge of this intersection point, indicating the need for interventions at this point in order to avoid potential accidents caused by conflicting movements [5].

The developed method allows identifying the best set of independent routes from the affected area to each destination point, considering both travelling time and capacity of the transportation network as parameters for analysis. For each destination point, two independent paths will be identified. With these, two independent paths selected from the origin to each destination point for different reasons. In the first place, it is important to have an alternative route in cases of infrastructure failure, road blocks or any unforeseen events. The disaster transportation network plan can also designate different flows for each path, so there will be a path with the flow from the disaster area to the destination point to which evacuation can be allocated and another with the flow from the shelter to the disaster area to which the transport of equipment, critical supplies and personnel from source to affected areas can be allocated. A circular flow can also be established, especially in cases of large-scale disaster. This measure can help to increase the speed of the traffic flow.

In the process of selecting these two independent paths, a *Volume Index* defined by the ratio of capacity over travel time is determined for each path, and the best route set is that which presents the largest sum of these indices. The reason to choose this index is because comparatively a path is better than other if it has larger capacity or a smaller travel time. Considering the possibility of existing independent *n*-paths between a pair of source and destination node in a network, the method determines a set of paths with the objective of maximize the summation of the ratio of each route. Besides, routes to different destinations points cannot have intersection points as well, so its use minimizes the problem of accidents and permits a continuous traffic flow.

Therefore, the method is applied iteratively, allowing the removal of intersection points among the different routes. To solve this problem it was developed the following algorithm shown in Fig. 3.

Time to time based on the new roads or highway or changes in urban aspects update it is vital to redesign the network plan to be more flexible, adaptable and to be able to improvise transportation network plan, therefore in case of disaster the transportation plan perfectly match and suitable to disaster transportation network plan targets.

During execution of disaster transportation network, it must gathered data and situation of network on real-time to modify and to optimize the disaster transportation network base on real-time situation and simulation of all possible scenarios ahead of time.

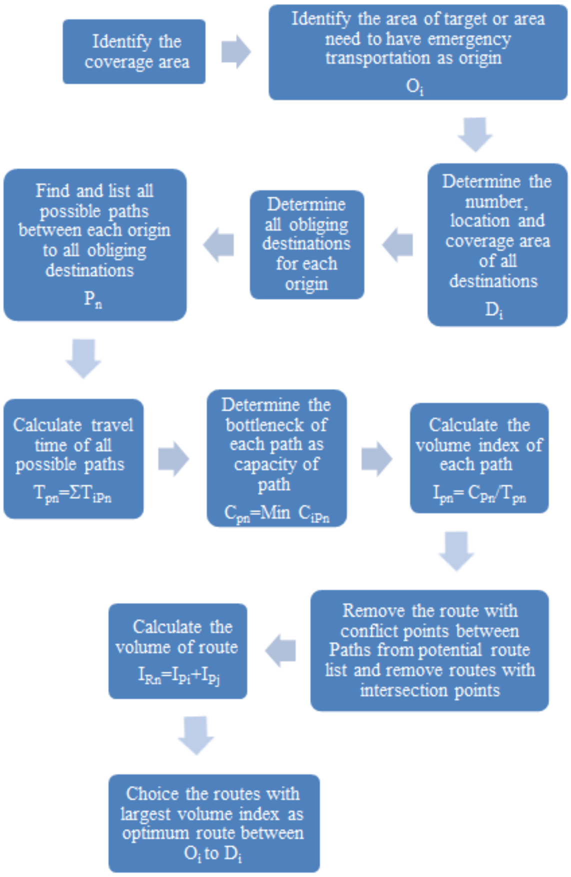

Figure 3. Heuristic model

V. Case Study

To clearly appreciate, to understand the benefits of this paper and to show the viability of the developed method the succeeding discussions are an application of the methods as an Evacuation Planning Exercise. In this exercise, a potential disaster area is defined, as well as actual shelters to which the affected population would be evacuated. Then the transport network, its capacity and travel time are defined.

The flow of vehicles to be evacuated has origin on disaster area and the central point of the potential disaster area should be evacuated immediately in the case of the effective event of the disaster. The destination nodes are Shelter I and Shelter II, predefined as actual shelters as shown in Fig. 4.

Among the different possibilities of routes in the proposed scenario, the method was able to identify two independent routes from each shelter to the disaster area, considering travel time and capacity of the transportation network as parameters for analysis.

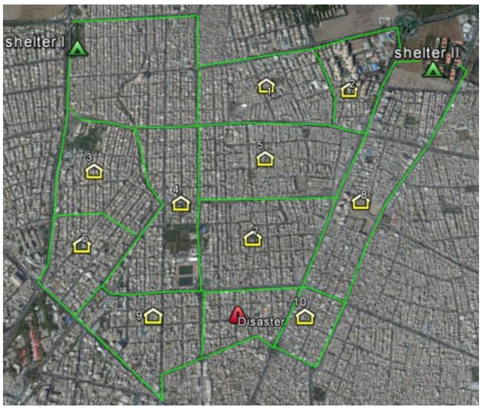

Figure 4. Designated disaster and shelter areas

All possible paths between disaster area to shelter I are listed in Table I.

TABLE I. ALL POSSIBLE PATHS BETWEEN DISASTER AREA TO SHELTER I

Path	Path	Path	Path
D-10-7-5-2-SI	D-7-10-8-SI	D-4-5-2-SI	D-9-4-5-2-SI
D-10-8-SI	D-7-10-8-2-SI	D-4-1-2-SI	D-9-4-1-2-SI
D-10-8-2-SI	D-7-5-4-1-2-SI		D-9-6-3-4-5-2-SI
	D-7-5-2-SI		D-9-6-3-4-1-2-SI

Identify the Bottleneck and define the Volume Indices (Cp/Tp) of each path

Estimated Travel Time, Capacity and defined Volume Indices of each possible path between disaster area to shelter I are represented in Table II.

TABLE II. CAPACITY AND VOLUME INDEX OF EACH PATH

Path	Travel Time	Capacity	I
D-10-7-5-2-SI	29	1000	34.48
D-10-8-SI	25	1500	60
D-10-8-2-SI	24	1200	50
D-7-10-8-SI	30	1200	40
D-7-10-8-2-SI	29	1200	41.38
D-7-5-4-1-2-SI	40	1000	25
D-7-5-2-SI	22	1000	45.45
D-4-5-2-SI	20	1200	60
D-4-1-2-SI	26	1000	38.46
D-9-4-5-2-SI	26	950	36.54
D-9-4-1-2-SI	32	950	29.69
D-9-6-3-4-5-2-SI	44	950	21.59
D-9-6-3-4-1-2-SI	50	950	19

Determine all possible independent routes from disaster area to shelter I, as shown in Table III and Fig. 5.

TABLE III. ALL POSSIBLE INDEPENDENT ROUTES BETWEEN DISASTER AREA TO SHELTER I

Route	Path	Travel Time	Capacity	I	ΣI
1	D-10-8-SI	25	1500	60	120
	D-4-5-2-SI	20	1200	60	
2	D-10-8-SI	25	1500	60	105.45
	D-7-5-2-SI	22	1000	45.45	
3	D-4-5-2-SI	20	1200	60	100
	D-7-10-8-SI	30	1200	40	

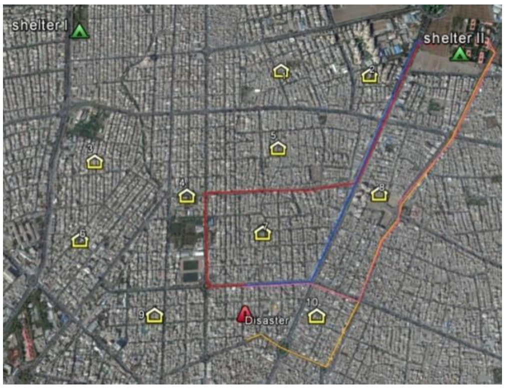

Figure 5. Possible independent routes between disaster area to shelter I

The inner potential of the network equals to greatest potential potent of the nodes of the network. Therefore, the inner potential for the analyzed network equals 1500 Veh/h. Comparing this value to the total additional flow that can go into the destination Shelter I and to the total additional flow that can possibly flow out of the source Disaster area. Therefore, the maximum potential of the network equals to 1500 Veh/h. Thus, the limit ratio C/T, that is, the ratio of highest total travel time among the paths from the last iteration, equals to 50, a value lower than the ratios of the two independent paths found so far. Therefore, there is no possibility of finding better route than route 1, so the route 1 is optimal.

The same procedure adopted to find the 2-independent paths from Disaster Area to Shelter II is used in this case as shown below in Table IV and Fig. 6.

TABLE IV. THE TWO (2)-SHORTEST PATHS IDENTIFIED FROM DISASTER AREA TO SHELTER II

Path	Travel Time	Capacity	I
D-4-1-SII	21	1450	69.04
D-9-6-3-SII	34	1100	32.3

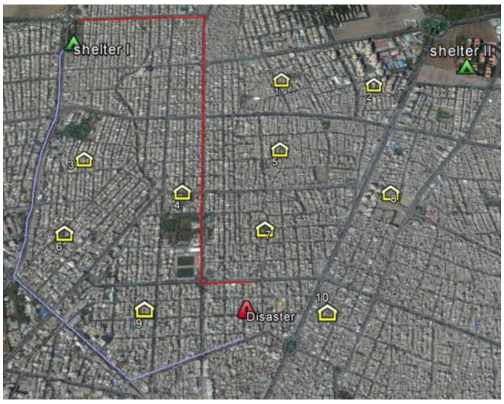

Figure 6. Possible independent route between disaster area to shelter II

TABLE V. THE TWO (2)–SHORTEST PATHS IDENTIFIED FROM DISASTER AREA TO SHELTER I, AFTER REMOVING NODE 4

Path	Travel Time	Capacity	I
D-7-5-2-SI	22	1000	45.4
D-10-8-SI	24	1500	62.5

Identify coincident nodes in the 2 sets of routes from disaster area to Shelter I and Shelter II shows node 4 is coincident to path D-4-5-2-SI and path D-4-1-SII.

The same procedure adopted to find the 2-independent paths from Disaster Area to Shelter I, before removing node 4, is repeated in this case, shown in Table V.

TABLE VI. THE TWO (2) – SHORTEST PATHS IDENTIFIED FROM DISASTER AREA TO NODE SHELTER II, AFTER REMOVING NODE 4

Path	Travel Time	Capacity	I
D-4-1-SII	21	1450	69.04
D-9-6-3-SII	34	1100	32.2

The same procedure adopted to find the 2-independent paths from Disaster Area to Shelter II, before removing node 4, is repeated in this case. However, when node 4 is removed, there is only one possible path from Disaster Area to Shelter II. Therefore, we should keep path D-4-1-SII, from the previous iteration, as an alternative shown in Table VI.

No coincident nodes were found in the 2 sets of two routes from Disaster area to Shelter I and II, so this is the best possible solution as shown below in Fig. 7.

Figure 7. Optimize independent routes between disaster area to shelter I and shelter II

VI. CONCLUSION

This study provides the dynamic method to develop sustainable disaster transportation network to facilitate traffic flow, to reduce potential accidents and to eliminate routes congestion under disaster situation.

Disaster transportation network provides the function of an effective mobilization under disaster situation on real-time particularly using the flowchart of *Optimize Disaster* Transportation *Network* which dynamically design, analyze and evaluate the disaster transportation network to minimize the travel time and to maximize the capacity of transportation network in the designated area.

And, the *Heuristics Method* which cannot only be applied for independent routes for developing in-place network plan but also can apply analytical techniques to define a set of optimal routes and transportation performance measures simultaneously.

In general, all the tasks should include the updated transportation network plan and use all necessary/applicable equipments/materials and knowledge to collect the real-time data during the events to optimize and to modify the disaster transportation networks.

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Alireza Moghayedi earned his Bachelor of Science in Civil Engineering from the Azad University of Iran in year 2004, Master of Science in Construction Management from the University of the East, Philippines and Master of Science in Civil Engineering Major in Transportation in University of the Philippines in year 2010 and 2013, respectively. Also, he is a candidate for Ph.D. in Civil Engineering Major in Transportation in University of the Philippines. From year 2010 to 2013, he was a faculty member, Director of Mathematics Program in several times, a Founder of Mathematics Consulting Group, and an author of Pre-College Mathematics to evaluate and improve mathematics knowledge and talent of Filipino college students at Far Eastern University, Philippines. He was a Co-Adviser in Graduate School of University of the East, Philippines from year 2010 to 2012. And lastly, he was a Co-Adviser in College of Engineering of University of the Philippines from 2012 to 2014.
Alireza Moghayedi is currently a Director II of Research and Technical Studies Department of Road and Urban Development Organization of Iran (Khorasan Razavi).

Helen D. Dillena graduated from Mapua Institute of Technology *(MIT)*, Manila, Philippines with a Bachelor of Science in Civil Engineering in year 2001, where she volunteered as Field Reporter at night, after class and every weekend. She passed the Board Examinations and soon hone her skills both in construction marketing and technical aspects to various reputable construction companies, private owners, governments agencies and etc. particularly to Contrete Ventures Group, Inc. During this time, she interested to management aspects and soon earned her Master of Science in Construction Management *(MSCM)* in the University of the East, Manila, Philippines in year 2009 while working and soon hone her skills and enthusiasm to develop construction techniques (Innovative Construction: Methods & Procedures for Concrete Floor System and etc.), to improve managerial program (Critique on Construction Management Contract and etc.) and to innovate both construction and management aspects through researching. She is also an active member and served as Director for four years in Mapua Institute of Technology Civil Engineering – Environmental Sanitary Engineering Alumni Association (MIT CE-EnSEAA).
Helen D. Dillena is currently an independent researcher and construction consultant.