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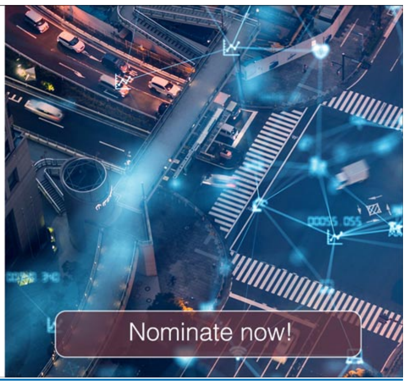

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# A review: Adaptation of escape route for a framework of road disaster resilient

**A A Redzuan[1], A N Anuar[1], R Zakaria[2], E Aminudin[2,3*], N E Alias[1], M A M Yuzir[1] and M R Alzahari[2]**

[1]Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, 54100 Kuala Lumpur, Malaysia
[2]School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia.
[3]UTM Construction Research Center, Universiti Teknologi Malaysia

[*]Corresponding author: eeydzah@utm.my

**Abstract.** Transportation system plays a vital role in sustaining the economic and social well-being of a community. Disaster or extreme hazard such as earthquake, storms, landslide, flood, terrorism, etc. has a major impact on the resilience of the road, especially in ensuring the impact toward the recovery for communities. Road infrastructure is linked to many encompassing factors such as road user, climate, economy, material, topography and periodic maintenance. Recently, unpredicted climate causes heavy rain, landslide, and flood resulting in high losses bared by the government on the repair and reconstruction works. Previous events have revealed that certain road areas in Malaysia are vulnerable after exposed to damage due to the natural disaster. This paper highlights the identified factors that contribute to adaptation on the escape route for road disaster resilient. A comprehensive review was done to identify a few missing approaches in the road network resiliency, which include a temporal route option as part of the adaptive routing solution. The research is expected to become a reference to overcome disruption in the road network in time of disaster or crisis while supporting the government initiative to strengthen the resilience of the nation's infrastructure.

## 1. Introduction

Land transportation system plays a vital role in sustaining the economic and social well-being of communities. On occurrence of extreme hazard such as earthquake, storms, landslide, flood and terrorism, the condition of such networks have a significant impact on the recovery of the community. [1-6]. Human activities are highly depending on road as a medium for traveling. Road is defined as a route or open way from one place to another [7]. Technically, roads can be referred to land transportation infrastructure that serves as a platform for movement of motor, wheeled vehicles. In the research world, the resilience of roads to handle disaster are divided into three main areas; 1) road network design, 2) emergency traffic management, and 3) evacuation route [8].

According to the emergency database (EM-DAT) on statistics of disaster events around the world [9], frequency of disaster events has increased and reached its peak in 2000, and have more than 350 happened every year in the last decade. Disaster tremendously degrades social quality and does more damage in developing countries, which makes the effort to rescue and relief operations more significant.

Human dependency on transportation systems has grown extensively at the same time, interference to such normalcy had created a void in the research area of transportation resiliency [10]. Studies to improve the efficiency of road function is necessary to deal with uncertain conditions that are capable of interrupting the normal functioning road system. Road disruptions are the usual outcome of any natural disaster causing a disconnection in the larger network [11]. Each road segment (link) or intersection (nodes) are measurable components that can quantitatively analyze network resiliency [12, 13]. Critical link of a network would bring the most severe impacts on the entire system upon failure [14]. Efforts on improving the road function in disaster are generally referred as the dependency of a reliable and efficient transportation network on providing accessibility while supporting the safe movement of victims and goods continually [15].

This paper highlights the factors that contribute to the adaptiveness of the road routing in countering network disruption due to disasters. A comprehensive review were made in order to identify a few missing approach in the topic of road network resiliency. This includes elements to be taken into consideration in evaluating network efficiency and method such as contraflow and temporal route option as part of the adaptive routing solution. Therefore, this paper aims to identify factors that contributed to the adaptation of escape route for a framework of road disaster resilient. The rest of the paper is organized as follows. Section 2 defines the research topic and discusses the previous research on road disaster resilient elaborating further into three topics. S*ection 2.1* elaborates on road performance in disaster phase, *Section 2.2* on road function in disaster phase and followed by routing method in *Section 2.3*. Section 3 discloses the findings and present the framework of road disaster resilient along with the parameters adapted by previous authors collectively. Conclusion is presented in Section 4.

## 2. Road disaster resilient research

In an operative environment, resilience is described as the ability of a system to return to normal condition after disruptive occurrences. Resilience describes the capability of system to "absorb", "adapt" and "recover" to disruptive events. Many are similar to already existing concepts such as robustness, reliability, flexibility, and survivability. Resilient system in the research world has been acknowledged since the last few decades considering the amount of concern in system security and the increasing trend of disaster occurrence throughout the world associated with the inevitable system disruption [16]. This paper focuses on the road network adaptability in responding to major disruption caused by natural disaster. Throughout the comprehensive literature review, every field circulating around the research area are recorded as indicated in figure 1 bubble diagram. This classification may vary depending on the researcher's point of interest.


**Figure 1.**Overview in the field of road resilience study.

In the earliest stage, we have identified a various field of research paper in the related area without considering the theoretical aspects and methodology. The nature of the research on the road resilient are technically based on analyzing efficiency on network design and performances, traffic management, and physical road infrastructure, which falls in the disaster-engineering category. Most authors incorporate demographic and social factor such as human behavior, user demand, road user and population [17, 13]. Other quantify the economic value on reducing cost, budget or optimizing resources. There are also studies on governance on who held the highest authority in resilience policy [18]. What made resilient study a breakthrough are those that are contributed in form of information technology such as artificial intelligence, remote sensing, big data and internet of things. This has contributed to the ease of data distribution made open access worldwide such as Open Street Map, satellite imagery, global positioning system (GPS), user interface, and social application.

Studies on road network resilience are also common, applied by concept development and performance measure of resilient network. In the current research, an analysis to quantify the resiliency of a system and a selection of recovery strategy is commonly explored. Another identified challenge is to develop a rigorous mathematical model of the recovery process [19]. A review of study on resilience measurement has identified the ongoing and upcoming research directions that are of interest to the resilience community; 1) Planning for resilience (optimization model), 2) Resilient interdependent processes and systems and 3) Standards for resilience [16].

### *2.1. Road performance in disaster phase*

Within disaster context, road infrastructure plays a significant role in all phases of disaster cycle. It is to provide adequate and continuity of service for evacuation, response to emergency, humanitarian supply and recovery process [17]. System performance curves under disruptive event is shown in figure 2. It provides a general overview of road performance with respect to a time-dependent system, mainly divided into three phases: pre-disaster, disaster phase, and post-disaster. The pre-disaster phase consists of prevention, preparedness and mitigative actions. A well-planned road infrastructure during this stage serves to avoid or minimize disaster impact through application of preventive and adaptive design, or known as proactive adaptation. This construction of road infrastructure does will only resist and endure future disaster, but will also guarantee a sustainable development by preventing unnecessary losses from the damage of surrounding environment [20]. In this stage, the road system operates in an original state, where both the system capacity and demand are sufficient. This period is also referred as "reliable" which enables the system to perform with adequate service for a certain period of time without fail and maintain the base performance.

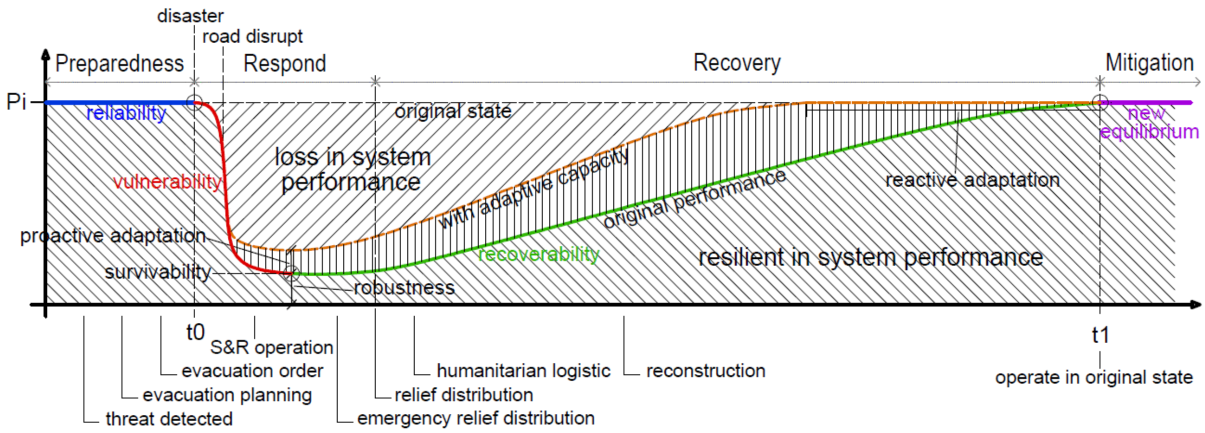


**Figure 2.** Schematic of road performance curve for disaster resilient [16, 21, 22].

During the disaster phase, responses to activity such as evacuation, search, and rescue are crucial. System performance severely drops once the disaster erupts at the time, t=0. In this stage, vulnerability impacts the direct decrease of the system performance until it reaches the lowest threshold, or known as survivability. Vulnerability here refers to the physical sensitivity of the system to disruptions, influencing the degradation of speed of its performance [23]. Both robustness and redundancy uphold the remaining function system as it responds immediately. Robustness is viewed as the availability of optional routes between origins and destinations, which can assist in mitigating the negative impacts of disasters to a transportation network. Finally, the post-disaster stage comprises of all recovery activities aiming at road restoration to its normal function [8]. Recovery planning is involved in rebuilding system accessibility and recovering its functionality as soon as possible. Strategic recoverability is also known as reactive adaptation. After the time recovery period, system stabilizes to the acceptable performance level, and therefore, a new cycle of system performance begins, referring to time, t=1. The new equilibrium can be different, either improvised if “build-back-better” or partially recovered for temporary purpose compared to the original state before disruptions.

### *2.2. Road function in disaster phase*

In the literature, relocation from areas at risk to areas of greater safety is referred to as an evacuation. The evacuation activities can be either voluntary, recommended, or mandatory, and should be conducted according to an evacuation plan controlled by levels of authority [24]. Figure 3 illustrates the evacuation process and road function based of several consecutive phases, which are an extension work from author Stepanov A. and Smith J. M. [23], merging road function into the period of disaster. In Phase 1, a threat is detected and announced by the local disaster agency. In Phase 2, decision makers evaluate the risk and potential threat for that specific areas. If the risk is high and there are no safe zone to provide adequate protections, an evacuation order should be issued. In this case, the evacuation zone is established as the destination. In Phase 3, the alert has to be communicated to the community. In Phase 4, communities prepare to leave. Phase 5 involve movement through the road network to the designated safe areas or shelter. Lastly, in Phase 6, evacuees arrive to safe destination and verify for missing victim and provide treatment for wounded. Phase 7 marks the beginning of recovery stage of any damaged infrastructure. The time intervals for Phases 3-6 represent the average time for all groups of evacuees, as these steps may have different durations for each class of evacuees [23]. Alteration in road system in disaster situation are adjusted according to the necessity, prioritizing to minimize the traveling time of human evacuation. Between the destination (shelter) and origin (affected area) of a road network, lies various possibilities of path to connect both locations.

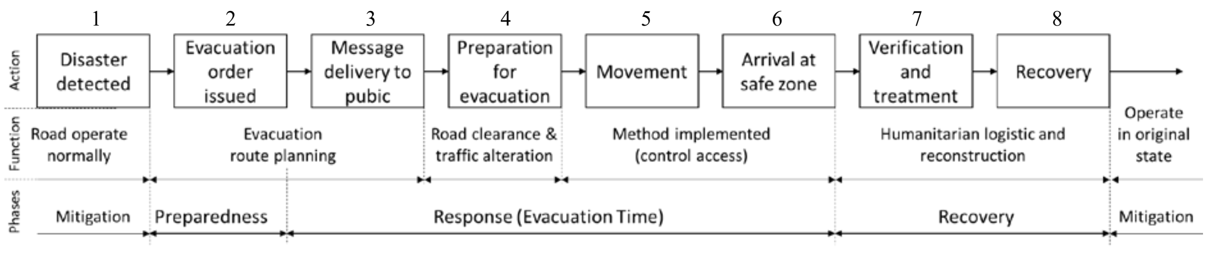


**Figure 3.** Function of road in evacuation phase.

The function of road infrastructure became critical and highly dependent in fronting the disaster, which in certain scenarios is complex. During the initial response phase, multiple and immediate mobilization occur simultaneously as victims are evacuating to safe zone and assist personnel on transferring vulnerable victims. This refers to the evacuation operation. Evacuation and logistics support are two major activities in disaster response [25]. For an extended period, the road is utilized by multiple stakeholders on providing supplies and services such as food, equipment, first aid material and healthcare sustaining the basic needs of victims in the affected area. Location of emergency bases are major issue that should be addressed in disaster management preparation plans [26]. This emergency relief operation is known as humanitarian logistic [27]. The final recovery phase operation adapts to the functional road network until the reconstruction completes. Hence, it operates as the original state.

*2.3. Routing method*
There are numerous models developed to obtain the most efficient routing solution. Route planning is foreseeing and avoiding any problem which may increase traveling time along the road during emergency phases. The objective of resilient network is to minimize any one or more of the following; 1) route cost, 2) route distance, 3) travel time, and 4) user dissatisfaction [28]. Apart from that, the technique applied should avoid problems such as accidents and congestion in an emergency situation. Experience from past events had evoked a major problem, which is the insufficiency of road capacity to handle the traffic surge during a large-scale evacuation operations converging to a limited number of exit routes [29]. Conventional method that relies on the shortest travel time [30] alone does not guarantee the efficiency of evacuation route.

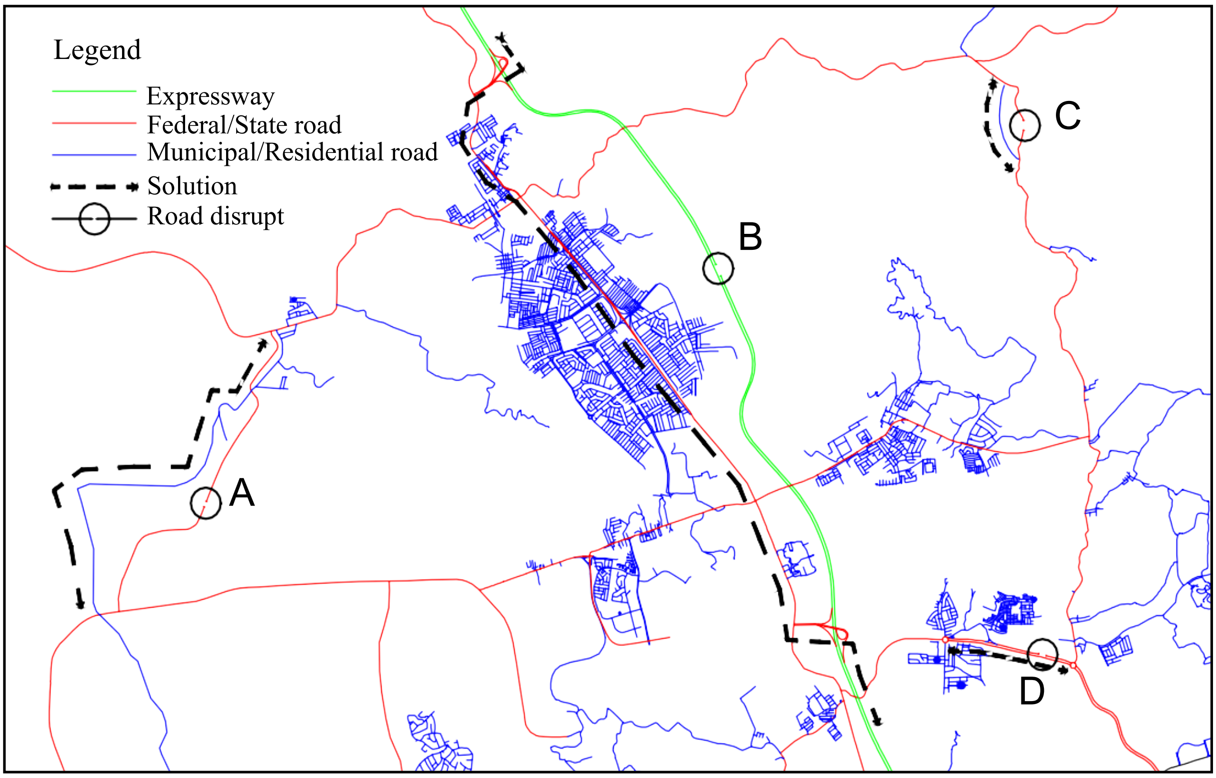


**Figure 4.** Routing method mapping.

**Table 1.** Routing method.

| Routing Solution | A Alternative route | B Independent route | C Temporal route | D Contraflow |
|---|---|---|---|---|
| Description | Shortest path alternative road | Allow traffic control for single direction flow | Create diversion road | Allow sharing of opposite traffic direction |
| Situation | Where there are availability of other route | Ease flow of heavy traffic | Weak or no alternative route, flexible surrounding | Access control road / highways |

Figure 4 displays a mapping of road network emphasize on four routing method in according to different scenario followed by elaboration in table 1. In any disruption of a road segment, a common solution would be to use alternative road of shortest path available (A). In a high capacity location where as a highway is disrupted, to ensure an efficient flow of traffic are to provide two independent route each supporting the continuous flow of a direction (B). In case of unavailability of other route such as isolated, mountainous or rural area, the surrounding environment must be flexible to construct a temporary diversion road (C). This method is the least explored in the research field. As for disruption on a one-way multiple-lane road, a solution of contraflow can be considered by sharing the undamaged side to the opposite movement of vehicle (D). This method requires an effort in traffic control but provides a solution for longer period recovery.

The method related to network reliability in reaching resiliency can be explored in two ways. One way is by developing algorithms to make the calculation of network reliability more computationally efficient [15]. This solves the complexity of computation application by complete state specifically in resolving practical networks. However, it is not possible to pinpoint the exact definition for reliability that corresponds to real situations. The other way is to focus on the formulation of new measures to calculate network reliability using non classical approaches.

Method of optimizing routing are an extended study by time. There are various element to take in consideration in finding the efficient routing solution. As mentioned by Aydin, Nazli Y. et al. [31], four strategies were evaluated based on the three used element; 1) closeness, 2) road hierarchy, and 3) time required for clearing the road. Kasaei, M. and F.S. Salman [32] conducted a study on restoring connectivity of a degraded road network, which optimizes the route of a road clearance to regain the connectivity of the road network which separated into several connected components in shortest time. Campos V., et al. [33] define two independent path to allow continuous traffic flow from disaster area (origin) to each shelter (destination) considering two element; 1) travelling time and 2) capacity of the road network as parameter for analysis. Sangho K. et al. [34] presented the solution of contraflow network reconfiguration incorporating road capacity constraints, multiple sources, congestion, and scalability.

The common objective of network routing analysis is to increase the effectiveness of vehicle flow in the critical situation. Even with the best solution obtain, a real scenario is more complex as road capacity are not influenced by the arc capacity, but other factors as well such as congestion effect, demand level, and route choice behavior of road users [35]. A review done by Psaraftis H. N. et al. [28] on studies related to the dynamic problems of vehicle routing, which identified research papers and arranged according to taxonomy of 11 criteria:1) type of problem, 2) logistical context, 3) transportation mode, 4) objective function, 5) fleet size, 6) time constraints, 7) vehicle capacity constraints, 8) the ability to reject customers, 9) the nature of the dynamic element, 10) the nature of the stochasticity, and 11) the solution method.

## 3. Framework of road disaster resilient

The proposed framework attempts to identify attributes contributing to the adaptation of escape route. The development of the framework in figure 5 is motivated by the effort in search of data required toward achieving the objective. The framework elaborates further, and several attributes may break down into lower levels of attributes (sub-attributes). Each attributes having their own value may influence the configuration of routing method depending on the reliability and availability of data.

Framework in figure 5 displays attributes arranged in three main factor for road network resilient. The main framework structure is adapted by an example from the World Bank: Climate-Resilient Transport Framework published by Jane O. E. and Nancy V. [36]. This arrangement is derived from the definition of vulnerability. The vulnerability of a transport system is a function of the potential impact, based on its exposure and sensitivity to climate change, and its adaptive capacity. However, the framework focuses on the resilient network as the main goal to resolve a road disruption event. Hence, the resiliency of a road network is a function of the road disruption, based on the existing road infrastructure, the occurred disaster, and its adaptive routing method.

Disaster usually became a concern by reports from public or road petrol on its location. It is followed by an investigation to gather detail information. In the earliest process of retrieving information, disaster type, size and location are verified for the selection of rescue mode. For example, disruption due to flood offer hydrological mode of rescue, and disruption due to a landslide on mountainous area requires additional air support. In the case of a typical scenario, affected areas will then be investigated to identify casualties and disrupted link. These are the disaster information which will then be integrated with the existing data on road physical infrastructure for network analysis. Existing road data are provided by the road operation unit arranged in a database system. This includes road network and physical property, to mention the commonly related; node, link, road hierarchy, speed limit, width, lane, control access, bottleneck, direction and capacity. By this stage, analyst is able to identify degraded network losing its efficiency or reduction in reliability resulting in isolation or congestion. A new routing solution to restore efficiency is then proposed to road operator for further traffic configuration to increase the overall performance. In the selection of efficient routing method, other necessary data beforehand are critical for mobilizing of respond team. Further planning of routing method will take in consideration of the current situation according to the disaster phase and the environment of the affected area. A minor case would be road blockage by object or debris and requires removal before reopening traffic for operation. A serious case would be a total disconnect on the road segment due to the collapsed embankment. This requires long period recovery and alteration in traffic movements such as independent route or contraflow.

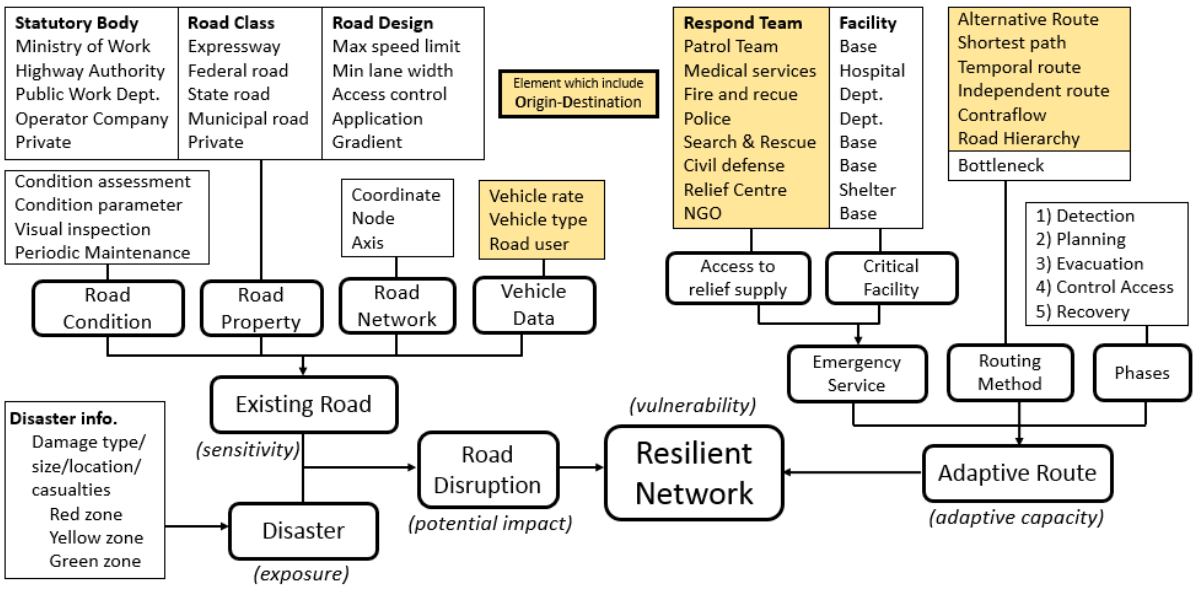


**Figure 5.** Adaptive routing solution framework.

## 4. Conclusion

An efficient network analysis, planning, and decision making for disaster operations are essential in obtaining reliable serviceability and functionality of the surviving network. This paper investigated the factors of adaptive routing in terms of network configuration engaged for the provision of services to road users and emergency services in a disastrous environment.

As most literature concern on minimizing travel time by measuring operational metrics such as link capacity, throughput and traffic flow, a few calculated travel cost indicate that disaster situation often distresses any budget limitation. In the strategy category, contraflow is less chosen as a solution for emergency traffic management. Undeniably, the consideration of bi-directional traffic in single flow traffic raises the problem complexity, although it may be a necessary option depending on the hierarchy as of highway along with proper execution for the operation. User behaviour has been rarely investigated, which assume that road users are willing to comply with orders on evacuation routes and make rational trip decisions. In some conclusion, even though disaster situation may deviate normal behaviours, road users will usually decide to use familiar routes despite not being recommended.

Another aspect that remains unexplored is a method of surveying on a network for a temporary route (diversion path) as a routing solution in a disaster-prone area. As most studies only offer the shortest alternate path route option, none have investigated the potential of constructing a diversion path for area weak in network connectivity.

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