EVALUATION OF POST-INCIDENT TRAFFIC MANAGEMENT MEASURES FOR EMERGENCY RESPONSE: A CASE STUDY OF KOLKATA CITY

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ABSTRACT
Emerging economies such as India are experiencing rapid urbanization and growth of private vehicles in urban areas, resulting in a significant imbalance between demand and supply of transport infrastructure which makes urban traffic management more complex in Indian cities. Occurrence of an incident can greatly intensify the existing congested traffic conditions at a location at a particular instant of time. Several factors of an incident situation such as location and time are expected to influence the decision-making process. Hence, the operational strategies need to be dynamic in nature to cater for incidents that are difficult to predict and such dynamic strategies should be implemented promptly. This paper presents an initial investigation to identify suitable dynamic measures for traffic management for different incident scenarios to ensure early arrival of emergency vehicles for relief and evacuation and to minimize the impact of such incidents on the traffic situation. The methodology has been demonstrated with reference to a road network in the CBD (Central Business District) area of Kolkata city. Several traffic management measures for incident response are identified by reviewing available literatures. Those measures are evaluated by two methods: (i) By Expert Opinion Survey and (ii) Using a micro-simulation model. Then the results from both the methods are analysed and compared. The outcome includes ranking of different measures for each of the incident scenarios based on the comparative study. If an incident occurs in a network, the top ranked traffic management measures for different scenarios are recommended for incident response.

1. INTRODUCTION
Rapid growth of vehicles coupled with infrastructure growth constrained by space and cost, makes traffic management an extremely challenging task in growing economies like India. In addition to recurring congestion that occurs regularly due to inadequate capacity and growing traffic demand, the non-recurring congestion occurring due to traffic incidents results in temporary and unexpected reduction in capacity, making the situation worse. The "Accidental Deaths and Suicides in India" published by the National Crime Records Bureau (NCRB) in 2015 reports about 1,48,707 deaths due to the road accidents in India, which is an increase by about 5.1% as compared to the previous year (*1*). Once a traffic incident occurs, it becomes a great challenge to conduct rescue and relief operations, especially in a congested transport network. In such situations, immediate response and quick recovery from the incident can be proved vital to saving lives, over and above the significant financial and social benefits such as reduction in travel times, reduced delays, lower levels of pollution etc. Also, due considerations need to be given to the type and severity level of the traffic incident and to the deployment locations of emergency response units (such as hospitals, fire stations, police stations, etc.). Several factors of an incident situation such as location and time are expected to influence the decision-making process. Hence, the operational strategies need to be dynamic in nature to cater for incidents that are difficult to predict and such dynamic strategies should be implemented promptly.

This study is motivated by the need for quick response in case of traffic incidents. This can be achieved by implementing various incident management strategies for early response and to control the flow of traffic in the influence area to facilitate the movement of Response units. Successful management of incidents on road networks involves both efficient detection of incidents (including identifying their location and nature, preferably by automated means) and identifying suitable treatment options, both in terms of removing or fixing the cause of the incident and managing vehicle flows during and after the incident. This requires coordination within and among the different response agencies like Police, Fire Department, Emergency Medical Service Department, etc. There is also a necessity for improving the existing practices followed in India which have not been very effective. The broad objective of this study is to identify and analyze different dynamic measures for traffic management for different incident scenarios to ensure early arrival of emergency response units for relief and evacuation and to minimize the impact of such incidents on the traffic situation. With this background, this study is demonstrated with reference to a road network in the CBD (Central Business District) area of Kolkata city.

2. LITERATURE REVIEW

Traffic incident may be defined as any non-recurring event that causes a reduction of roadway capacity or an abnormal increase in demand. Such events include traffic crashes, disabled vehicles, spilled cargo, fire, road debris, explosion, highway maintenance and reconstruction projects, and special non-emergency events (*2*). Traffic incident can also be defined as an emergency road user occurrence, a natural disaster, or other unplanned event that affects or impedes the normal flow of traffic (*3*).

Traffic incident management can be described as an array of activities that take place during four main stages: detection, response, clearing and recovery (*4*). The main elements of incident management include Incident Detection, Incident Verification, Incident Response, Incident Clearance, Site Management, and Motorist Information. All these elements impact the efficiency and success of the incident management system individually and collectively. Detailed, well-organized management systems or plans have proven beneficial in communities that implement them by reducing delay and creating more predictable travel times (*5*). Rapid detection is necessary to minimize the period of time during which roadway capacity is reduced. Verification is the process of determination of the exact location and nature of an incident and is required to reduce the time required to deploy an appropriate response to the scene of incident. Timely and effective responses reduce the incidents duration, and therefore, the time of roadway operation at reduced capacity. Clearance of an incident is the safe and timely removal of the incident and termination of incident conditions. It also includes clearance of non-functional vehicles (if any), debris etc from the roadway. The major goals of the recovery phase are to restore traffic flow conditions to normal, to prevent more congestion as new vehicles join the queue and prevent congestion from spreading to other portion of the transport network. Effective site management is required for the safety of crash victims, motorists and responders. It helps in coordinating responder activities and decreases the impacts of incidents on the transportation system.

Incident response is one of the important phases of Traffic Incident Management (TIM). In such a study, a model was built up for solving various network optimisation problems (*6*). Out of these, one problem deals with resource allocation strategy for emergency and risk management. The main aim was to reduce response time which is defined as the sum of dispatch and travel time for emergency response vehicles. In another study, an integrated decision-making framework was developed for reducing freeway-incident delay through the minimization of the duration of the incident (*7*). The focus of the study was on the mathematical model that will improve freeway incident management and the deployment of incident response strategies. Incident delay depends heavily on the total incident-remedy time, so the reduction of the dispatch and travel time of the traffic flow restoration unit is expected to result in substantial savings of incident delay. Another study was done based on incident response logistics and the effective deployment of incident response resources (*8*). The objective was to develop a support system that will provide districting, dispatching and routing of response units. Another related study focused the traffic incident response research on the appropriate resource allocation (*9*). The goal was to determine the optimal hours of operation, fleet and crew sizes, dispatching policies, areas of operation, and routing patterns, in order to maximize the response system's efficiency. Another study analyzed possibilities of traffic surveillance to improve traffic incident response system and reduce incident induced costs for the travellers (*10*). In that case, a Dynamic Traffic assignment (DTA) system was used to improve wide-area incident response through information sharing and coordination.

In a different approach, the benefits of various incident management strategies and technologies were evaluated using an integrated simulation tool (*11*). This tool was able to generate incidents and test various response strategies and technologies. The evaluated strategies were found to show positive impact on reducing incident durations while being cost-effective. Another study used a DTA model as a tool for preplanning strategies for managing major freeway incidents (*12*). It was found that the best response action to a given incident scenario was not necessarily intuitive; implementing the wrong response could worsen congestion on the directly impacted roadway and its surrounding network. The simulation also showed that congestion increases with delayed response, underscoring the benefits of preplanning to speed the implementation of effective incident response actions. The study considered only ramp metering as a response to defined incident conditions and examines only one incident location, while not explaining the choice of that particular location. The study compared the effectiveness of incident response strategies on the freeway level and on the network wide level with alternate routes included. The test of the response time effectiveness showed that the longer response time increases congestion but not significantly (*13*). In another study, different incident scenarios and the corresponding incident management strategies were evaluated with the help of a micro-simulation model (*14*). The analysis of the model outputs predicted the most feasible strategies for different incident scenarios. In another approach, a multiperiod optimization model was proposed based on the maximal covering location problem for optimizing incident response time (*15*). Another study proposed an advanced strategy for distributing incident response units by solving a non-linear stochastic programming problem (*16*).

From the point of view of traffic diversion planning during or after incident, effective and efficient diversion planning could minimize user travel time and cost (*17*). Diversion of upstream traffic results in a considerable reduction in demand flowing past the incident point, i.e. before the incident is cleared, and during the dissipation of traffic, after the incident is cleared. Another study implied the potential negative impact of diversion strategies on alternate routes (*18*). They emphasized the need to analyze operational characteristics of both the main roadway and alternate routes before implementing the diversion. Some of the other contextual approaches based their evaluation of diversion strategies on several case studies. A particular approach used a microscopic traffic simulator to evaluate the traffic control design (*19*). The approach was to measure total network travel time and origin-destination (OD) specific travel times. The results showed that even when route diversion reduced the demand for the ramp, the bottleneck formed later and a larger mainline disturbance was generated. Another approach emphasized both positive and negative impacts of traffic diversion (*20*). The main research question of the study was whether using alternate route can actually save driver's travel time. Traffic simulations were conducted to compare travel times on original and alternate routes. The simulation results from the case study provided multiple benefits for drivers using the alternate route.

The literature defines response time as 'dispatch time' for emergency vehicles. Incident Management Systems (IMS) consist of following three sub systems: (i) Incident detection, (ii) Incident Response Logistics (IRL) and (iii) Motorist Information and Traffic Management (*8*). The focus of this paper is on Incident Response Logistics.

3. METHODOLOGY

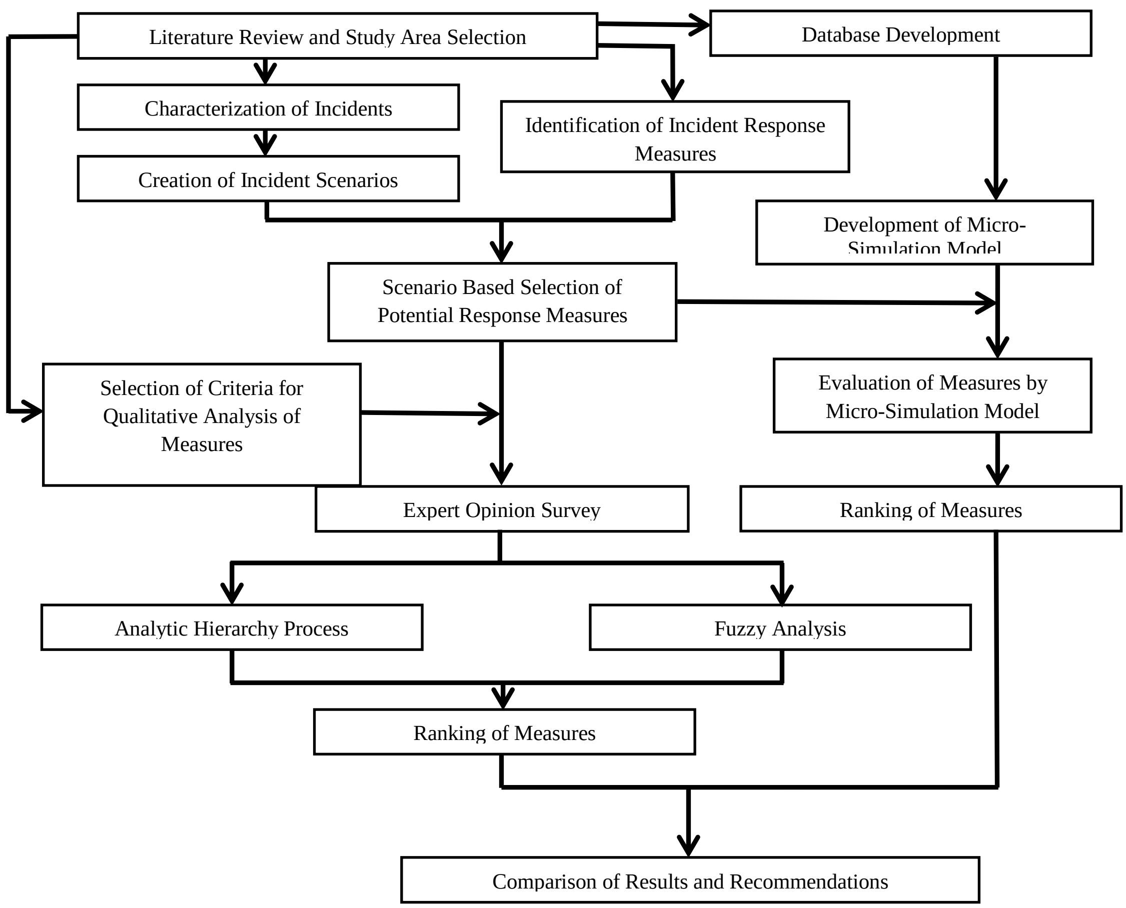

FIGURE 1 Methodological framework of the study

The broad methodological framework of this study is presented in Figure 1. Initially a detailed and thorough study of literature is carried out regarding incidents, types of traffic incidents and management measures during traffic incidents as mentioned in the previous section. The study area is selected in consultation with the local law enforcement agency (Kolkata Traffic Police). Based on the literature review, the incidents are classified by considering attributes contributing to different levels of incidents. The next step is to identify measures and principles of response. The next step is the selection of measures under suitable strategies. Then from the merits, limitations and suitability of measures, suitable measures are listed for different scenarios. This is followed by selection of criteria for qualitative analysis of measures. Then expert opinion survey is conducted. Weights for each criterion are decided using Analytic Hierarchy Process (AHP) and for each scenario the measures are assessed qualitatively based on fuzzy logic of analysis. Then overall scores are calculated; and based on this scoring, ranking of the measures for different incident scenarios were done. The traffic management measures are also evaluated by a micro-simulation model using VISSIM software. The study network has been developed in VISSIM for incident simulation. For developing micro-simulation model, different types of traffic data are required in different points of time. The collected raw data are then properly extracted and refined as per the needs. All the network geometry data and traffic signal control data are collected with the help of Kolkata Traffic Police. The existing traffic circulation pattern and the current practice regarding incident management are also noted. The total incident-induced delay caused in the network & the travel time of the Emergency Response Unit (ERU) to reach the incident location for incident response purpose are used as Measures of Effectiveness (MOE) for the evaluation purpose. Then the results from both the expert opinion survey and the micro-simulation model are compared. The outcome includes ranking of different measures for each of the incident scenarios based on the comparative study. If an incident occurs at a location in the network, the top ranked traffic management measures for different scenarios are recommended for incident response.

4. STUDY AREA

The study area considered in this research is the CBD area of Kolkata city. A few sensitive locations were identified and finally the particular study area is selected in consultation with the local law-enforcement agency (Kolkata Traffic Police). The area is marked with some busy and congested streets where some old and vulnerable buildings and factories are located, thereby, making this area highly sensitive to incidents. The boundaries of the area are defined by four major arterial roads namely, Chittaranjan (C.R.) Aveneue on East, Strand Road on West, Mahatma Gandhi (M.G.) Road on North, and S. N. Banerjee Road on South. The study network consists of 85 intersections, 45 of them being signalized ones and the rest 40 intersections are minor and unsignalized. This area is marked with a wide variation in carriageway widths, ranging from 6 m to 35.6 m. A few extremely important buildings and infrastructure facilities (Writers Building, Raj Bhawan, Kolkata Police Headquarters, General Post Office, SBI Headquarters, Regional Passport Office, The Lalit Great Eastern Hotel, Central and Chandni Chawk metro railway stations etc.) are located in this area, making this area highly attractive in terms of trip generation.

With regards to the current practices for emergency response in Kolkata, when an incident occurs, first, the respective traffic guard is informed to convey messages to the nearest Police Station, Central Traffic Control, Fire Station (if necessary). The whole city of Kolkata is under constant surveillance with around 700 CCTV cameras. After the traffic guard has conveyed the message, depending upon the severity of the incident, KARMA (Kolkata Accident Rescue & Medical Assistance) ambulance (with specialized paramedical staffs, police personnel) is deployed. If required, Fire Service Directorate Control room is contacted by traffic control room. The injured person(s), if any, is/are taken to the nearest Government Hospital. Every traffic guard has one ambulance and one wrecker; the ambulances are placed in strategic locations. If the incident is major and traffic needs to be diverted, the diversion plan is based on the experience of the key personnel. Also news of the incident is circulated via social media (Facebook page updates), loud-speakers, broadcasting to F.M., digital display boards (though in less numbers), etc. The outline of the area is shown in Figure 2.

FIGURE 2 Outline of the study area

5. DEVELOPMENT OF INCIDENT SCENARIOS

The methodology proposed here is developed to identify various combinations of traffic incident scenarios on Kolkata network. While no well-accepted standards exist yet for classification of different types of incidents, reasonable estimates are taken into consideration. The incidents are classified in four different levels (Level 1, Level 2, Level 3 and Level 4) based on four attributes as shown in Table 1.

TABLE 1 Classification of Incidents

Attributes	Level 1	Level 2	Level 3	Level 4
Nature of Requirement	Wrecker (1-2) and/or Ambulance (1-2)	More than 2 Ambulances or Wreckers. If fire is involved < 2 Fire Brigade (FB) from single source.	Multiple ambulances, wreckers are required. If fire is involved multiple FB (from multiple sources)	Involvement of multiple rescue units, big cranes, special agencies like bomb squad, army, etc.
Duration	< 1 hr	< 2 hr	>2 hr	> 2 hr
Intervention on Routes	Limited	Limited	Multiple	Multiple
Organization Involvement	Limited	Limited	High	High

There are three important factors in defining the problems related to different types of incident scenarios. The first factor is incident type as discussed above. The second factor is general impact of incident on traffic flow which can be represented by level of closure. An incident blocking one lane has a different impact as compared to an incident causing full blockage (in both directions). The third factor is volume of traffic flow at the time of incident which can be represented by the time of incident. In peak hours (morning peak and evening peak) the volume is very high. In Off- Peak hours the volume is considerably low. In lean hours (late night till early morning) the volume of traffic is very low. So if any incident occurs during lean hours, there is no need for special incident management strategies or measures. With these considerations, various combinations with level of incident, level of closure, and time of occurrence can be developed. Since no strategy would be required in lean hours, such cases can be ignored. For ease of analysis, incidents of Level 1 and Level 2 with level of closure of up to 50% of carriageway width can be grouped in single level called Level A and similarly, incidents of Level 3 and Level 4 with level of closure of 50%-100% of carriageway width can be grouped in another level called Level B. Based on Level A and Level B with the combination of Peak and Off-Peak hours, following four scenarios are developed:

Scenario 1: Level A incident occurring in Off-Peak hours.
Scenario 2: Level A incident occurring in Peak hours.
Scenario 3: Level B incident occurring in Off- Peak hours.
Scenario 4: Level B incident occurring in Peak hours.

6. TRAFFIC MANAGEMENT STRATEGIES FOR INCIDENT RESPONSE

The objective of formation of the strategy is to develop and to define a pre-fixed action plan in which different measures are compiled and the most appropriate ones can be chosen and implemented for specific situations. Strategy is defined as bundle of pre-defined measures. The incident response strategies are classified in three groups namely, Traffic Diversion strategy, Traffic Control strategy and Prioritization Strategy for Response Units (*21*). Various measures are identified in each group of strategy as shown below.

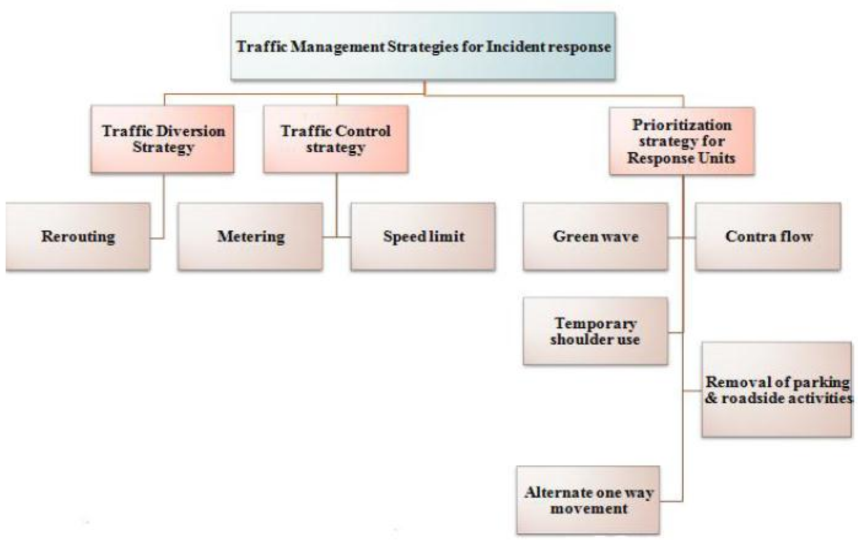

FIGURE 3 Traffic management strategies for incident response

Traffic Diversion Strategy involves the determination of where and how much traffic should be diverted and the sequence of roads. The effectiveness of traffic routing depends on the availability of alternate routes and level of congestion existing on those alternative routes. This measure is suitable in places where diversion can be done easily and it can be applied in all kinds of traffic conditions (peak and off-peak). Traffic Control Strategy has been developed so as to provide coordinated, traffic-responsive control in large-scale urban networks, in cases of traffic incidents. It involves the modification of signal timing or applying some limit of speed to reduce the flow approaching towards the incident location. Traffic control strategy includes following two measures for incident response (i) Metering and (ii) Speed limit. Metering regulates traffic access to the mainline and is usually suitable for peak hours to restrict or reduce the traffic flow towards the incident location. Speed limit is used to post a speed limit that is appropriate for current conditions and can be applied in all kinds of traffic conditions. Prioritization Strategy for Response Units includes measures which directly affects the movement of Response Units. It helps in quick movement of Response Units by applying various measures such as green wave, contra flow, alternate one way movement, temporary use of shoulder, removal of parking and roadside activities. Green wave is a system which is used to provide clearance to any emergency vehicle by turning all the red lights to green on the path of the emergency vehicle, hence providing a complete green wave to the desired vehicle. Contra flow operation involves reversal of traffic flow of one or more inbound lanes for outbound traffic. Alternate One way Movement is when two-way traffic is reduced to one-way traffic and traffic in both directions must use a single lane according to the direction of response vehicles. Temporary shoulder use allows roadway shoulder utilization to provide additional capacity around the incident scene. The four different kinds of scenarios and the contextual appropriate measures identified are as follows:

TABLE 2 Scenario Based Selection of Potential Response Measures

Scenario	Description	Measures
Scenario 1	Level A incident occurring in Off-Peak hours	1. Rerouting 2. Speed Limit 3. Contra Flow
Scenario 2	Level A incident occurring in Peak hours	1. Rerouting 2. Metering 3. Speed Limit 4. Green Wave
Scenario 3	Level B incident occurring in Off-Peak hours	1. Rerouting 2. Speed limit 3. Contra flow 4. Alternate one-way movement
Scenario 4	Level B incident occurring in Peak hours	1. Rerouting 2. Metering 3. Speed limit 4. Green wave 5. Temporary use of shoulder 6. Removal of parking and road side activities

7. ANALYSIS AND RESULTS

7.1 Selection of Criteria for Qualitative Analysis of Measures

Based on literature review, five factors for qualitative assessment of measures were identified namely, (i) Effectiveness of the measure, (ii) Ease of implementing the measure, (iii) Financial cost of implementing the measure, (iv) Impact of measure on other traffic and (v) Level of coordination among related agencies. Each measure is assessed individually based on these five factors.

7.2 Expert Opinion Survey

This analysis is divided in two parts. In the first part, Analytic Hierarchy Process (AHP) is used to find the weightage of each of the previously mentioned five factors. In second part, Fuzzy Logic is applied to find the final rankings of each measure.

7.2.1 Analysis Using AHP

In making a decision, the factors that are important are chosen for that decision. In AHP, those factors are arranged in a hierarchy structure (*22*). It provides an overall view of complex relationship among all the factors. AHP helps to assess whether the factor in each level are of same magnitude or not. If not then it helps in finding the weightage of all factors. Here AHP survey is done by using twelve Experts' ratings. The calculated weightage of each factor is summarized below.

TABLE 3 Weightage of Factors Based on AHP

Factors	Weightage
Effectiveness	0.346
Ease of Implementation	0.163
Financial Cost of Implementation	0.177
Impact on other traffic	0.141
Level of coordination	0.173

7.2.2 Fuzzy Analysis

Data are collected from the experts based on fuzzy variables (Very Low, Low, Moderate, High, and Very High) for each measure for each scenario. The experts have to define the range of fuzzy variables on a scale of 0-100 based on their perception. Then, they are asked to rate the suitable measures for each scenario, for each factor in terms of fuzzy variables (*23*). This process is called Fuzzification. Using the weightage and fuzzy values, Defuzzification is done using centroid method. Subsequently final score is obtained for each measure for each factor for the respective scenario. Based on final score, each measure is ranked respectively for all the scenarios. Here Fuzzy analysis is done by collecting five experts' opinions for each scenario.

The steps involved are as follows:

1. Collection of data (Expert Opinion) on Fuzzy Scale of 0-100
2. Identification of membership functions for each expert.
3. Applying average ordinate method for defuzzification process.
4. Obtaining defuzzified score (x)
5. Calculate Overall Score (Y) for each measure

Overall Score (Y) for each measure is calculated by using the following equation:

$$\mathrm{Y} = a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5x_5$$

Where a_i = weightage of factors obtained by AHP for each measure and x_i = values obtained by defuzification of the variables collected from the expert survey. The results are as given in Tables 4 – 7.

TABLE 4 Ranking of Measures for Scenario 1

Measures	Overall Score	Rank
Contra Flow	48.273	1
Rerouting	40.241	3
Speed Limit	47.089	2

TABLE 5 Ranking of Measures for Scenario 2

Measures	Overall Score	Rank
Green Wave	61.389	1
Rerouting	57.821	2
Metering	53.531	4
Speed Limit	55.693	3

TABLE 6 Ranking of Measures for Scenario 3

Measures	Overall Score	Rank
Contra Flow	53.775	2
Rerouting	49.245	3
Speed Limit	49.182	4
Alternate One way movement	58.195	1
Removal of parking and roadside activities	41.308	5

TABLE 7 Ranking of Measures for Scenario 4

Measures	Overall Score	Rank
Green Wave	52.607	1
Rerouting	39.813	6
Metering	42.642	5
Speed Limit	51.466	2
Temporary use of shoulder	49.694	3
Removal of parking and roadside activities	45.656	4

7.3 Development of Micro-Simulation Model

The test network for the study area for incident/ response modelling is developed in VISSIM using network coding. For this analysis, one mid-block incident location (on Ganesh Chandra Avenue) and one ERU deployment location (Lalbazar Police Headquarter) are considered. The study network along with the incident location (shown as orange circle) and the ERU deployment location (shown as blue map marker) is presented in Figure 4.

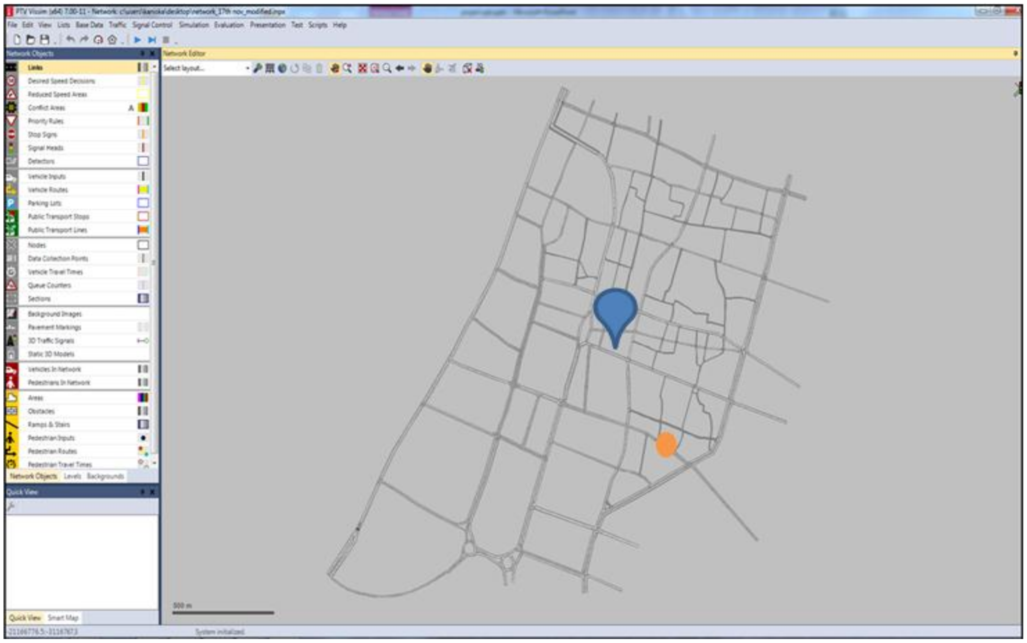

FIGURE 4 Study network in VISSIM

Defining the incident in the VISSIM simulation is done through time-dependent speed reduction areas and signal heads. Incident Location is represented by placing a traffic signal head to model the incident. Lane Closure determines the number of signal heads, with one signal head per each lane closed at the Incident Location. Incident Duration defines the "red" time of the signal used for incident modelling. Speed reduction areas are defined before and after the traffic signal to make sure the vehicles comply with incident conditions and slowdown in the area of lane closure. The database required for the micro-simulation model include link traffic volume, turning movements, average travel time, vehicle composition and routing decisions. All the network geometry data (carriageway width, lane configuration, width of median etc.), traffic signal control data (signal cycle length & its variation over different hours of a day, number of phases, green splitting, change interval, clearance interval etc.) and existing traffic circulation patterns are collected on-site. Capacities of all the roads in the study network are calculated in accordance with IRC: 106-1990 (*24*). The four incident scenarios are considered for the assumed incident location and the response measures are evaluated using VISSIM for both peak and off-peak hours.

7.4 Evaluation of Measures Using Micro-Simulation Model

In this stage, the calibrated micro-simulation model is used to evaluate different incident response measures (along with the do nothing alternative) for each and every incident scenario via simulation runs. All the model variables, input, and output parameters are needed to be fixed prior to the simulation runs. Minimizing the measures of effectiveness (MOE) forms the basis of evaluation. The total incident-induced delay caused in the network & the travel time of ERU to reach the incident location for incident response purpose are used as Measures of Effectiveness (MOE) for the evaluation purpose. The measures 'Temporary use of shoulder' and 'Removal of parking and roadside activities' are ignored while evaluating as provisions of those measures are not considered while developing the micro-simulation model. All the other response measures are modelled using signal timing modifications and time-dependent speed reducing areas. The evaluation results are shown in Figures 5-8.

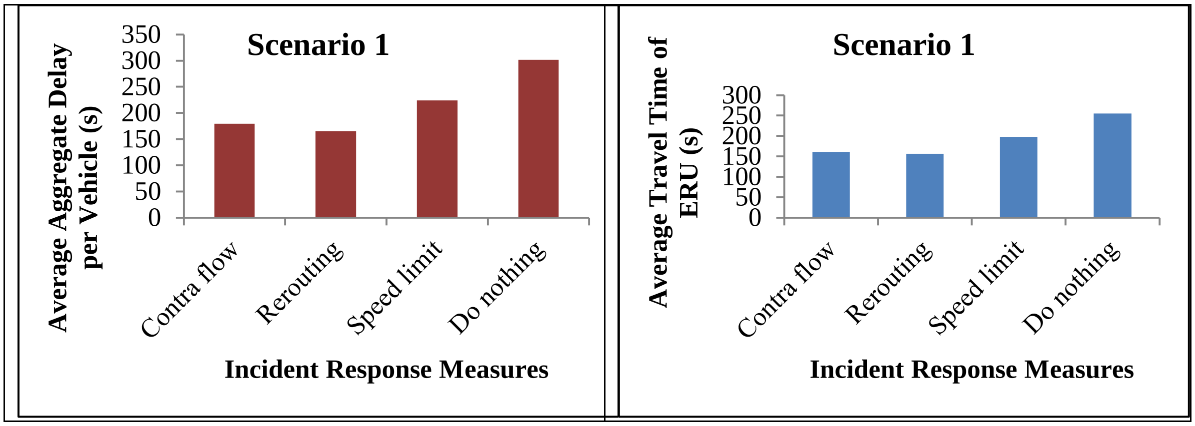

FIGURE 5 (a) Aggregate delay comparisons and (b) ERU travel time comparisons for Scenario 1

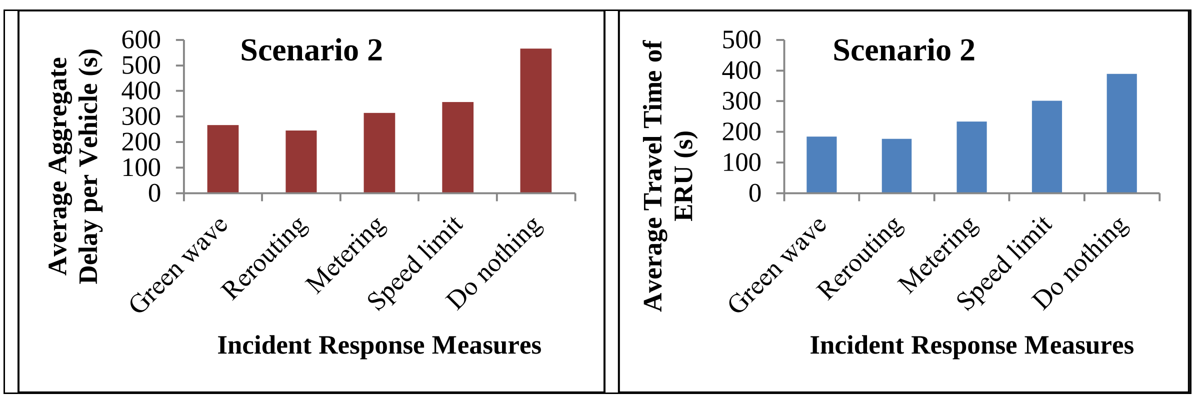

FIGURE 6 (a) Aggregate delay comparisons and (b) ERU travel time comparisons for Scenario 2

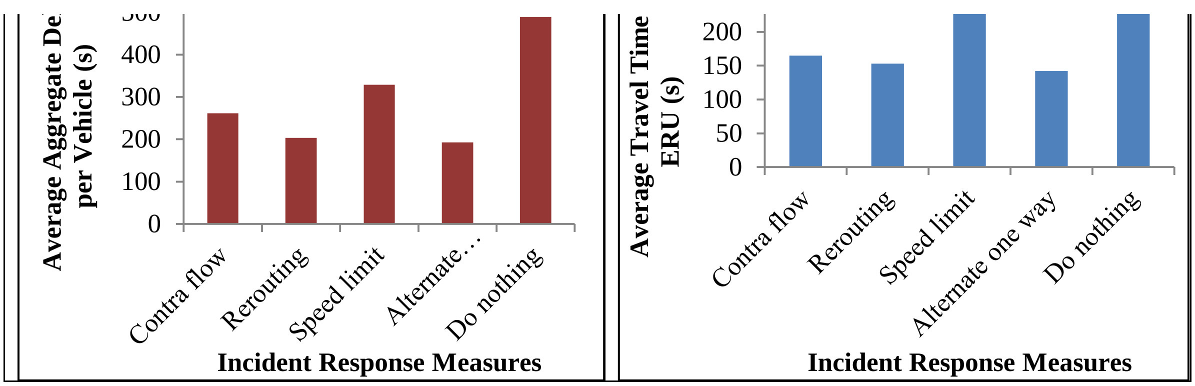

FIGURE 7 (a) Aggregate delay comparisons and (b) ERU travel time comparisons for Scenario 3

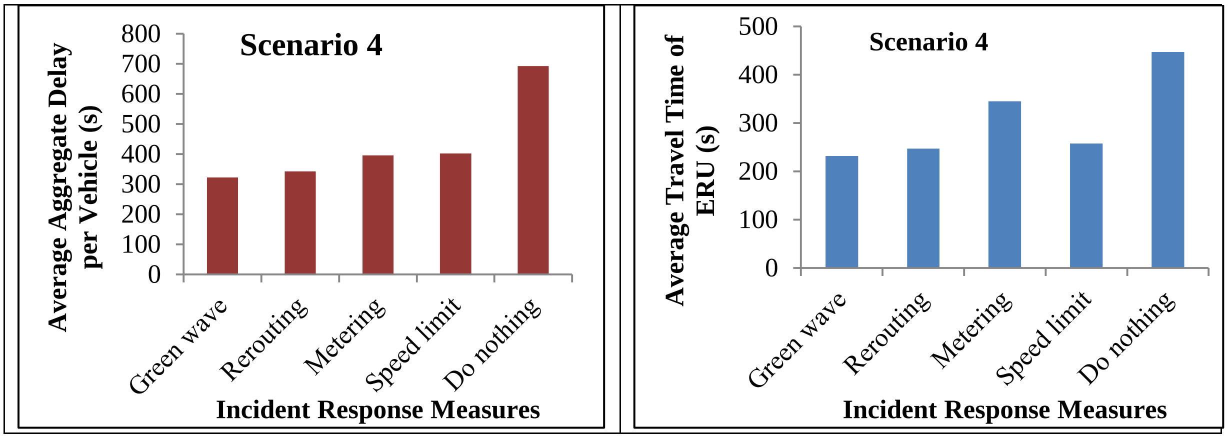

FIGURE 8 (a) Aggregate delay comparisons and (b) ERU travel time comparisons for Scenario 4

8. CONCLUSIONS

The results of simulations study and AHP-fuzzy analysis are generally in agreement, though with slight variations. The simulation study results indicate that the suggested measures are effective in reducing the aggregate delays and travel times, over the do-nothing situation. For Scenario 1, it is observed that while expert opinion analysis ranks contra flow as the best measure, simulation results rank it as the second best measure after rerouting. For Scenario 2 too, a similar result is obtained. While AHP-fuzzy analysis ranks green wave as the best option, simulation results indicating green wave as the second best option to rerouting. For Scenarios 3 and 4, both simulation study and AHP-fuzzy analysis are in agreement. While alternate one-way movement is recommended by either study for Scenario 3, green wave is suggested for Scenario 4.

The study is effective in identifying suitable dynamic response measures for incidents and also their ranking, based on the suitability for different traffic scenarios. Further study involves studying strategies, which are combinations of various response measures and their effectiveness. More numbers of possible incident scenarios can also be considered by taking account of more incident categorizing variables. The scope of simulation analysis can be more expanded by considering more than one incident locations and ERU deployment locations. Considerations of land use pattern and on-street parking can also be included while constructing the micro-simulation model in VISSIM.

REFERENCES

- National Crime Records Bureau. *Accidental Deaths and Suicides in India*. Ministry of Home Affairs, Government of India, 2015.
- Farradyne, P. B. *Traffic Incident Management Handbook.* Federal Highway Administration, U.S. Department of Transportation, 2010.
- *Manual on Uniform Traffic Control Devices*. Federal Highway Administration, U.S. Department of Transportation, 2009.
- Reiss, Robert A., and Walter M. Dunn Jr. *Freeway Incident Management Handbook. Final Report*. No. FHWA-SA-91-056, 1991.
- Fink, Kenneth L. Analysis of Incident Management Programs in North America. *Graduate student papers on advanced surface transportation systems*, 1993.

- Subramanian, S. *Optimization Models and Analysis of Routing, Location, Distribution, and Design Problems on Networks*. Diss., 1999, Chapter 5.
- Zografos, K. G., T. Nathanail, and P. Michalopoulos. Analytical framework for minimizing freeway-incident response time. *Journal of Transportation Engineering* 119.4, 1993, pp. 535-549.
- Zografos, K. G., K. N. Androutsopoulos, and G. M. Vasilakis. A real-time decision support system for roadway network incident response logistics. *Transportation Research Part C: Emerging Technologies*10.1, 2002. pp. 1-18.
- Pal, R., and K. C. Sinha. *Optimal design of freeway incident response systems*. FHWA/IN/JTRP-99/10. Purdue University, Indiana Department of Transportation, and U. S. Department of Transportation Federal highway Administration, 2000.
- Chauhan, A. S. *Development and Evaluation of Diversion Strategies under Incident Response using Dynamic Traffic Assignment System*. Doctoral dissertation, Northeastern University, 2003.
- Ozbay, K., W. Xiao, G. Jaiswal, and B. Bartin. *Evaluation of Incident Management Strategies.* No. FHWA-NJ-2005-020. New Jersey Department of Transportation Bureau of Research and U.S. Department of Transportation Federal Highway Administration, 2005.
- Wirtz, J. J., J. L. Schofer, and D. F. Schulz. Using Simulation to Test Traffic Incident Management Strategies. *Transportation Research Record: Journal of the Transportation Research Board*. No. 1923, Transportation Research Board of the National Academies, 2005. pp. 82-90.
- Martin, P. T., P. Chaudhuri, I. Tasic, and M. Zlatkovic. *Freeway Incidents: Simulation and Analysis*. No. MPC Report No. 10-229D. Mountain-Plains Consortium, 2011. pp. 11-34.
- Ghosh, K., and B. Maitra. Evaluation of Post-Incident Traffic Management Strategies: A Case Study of Kolkata City. Presented at 12th Transportation Planning and Implementation Methodologies for Developing Countries, Mumbai, 2016.
- Dell'Olmo, P., N. Ricciardia, and A. Sgalambro. *A Multiperiod Maximal Covering Location Model for the optimal location of intersection safety cameras on an urban traffic network*. Procedia-Social and Behavioral Sciences, 108, 2014. pp. 106-117.
- Park, H., A. Shafahi, and A. Haghani. A Stochastic Emergency Response Location Model Considering Secondary Incidents on Freeways. *IEEE Transactions on Intelligent Transportation Systems*, 2015. pp. 1-12.
- Hobeika, A. G., R. Sivanandan, S. Subramaniam, K. Ozbay, and Y. Zhang. Real-Time Traffic Diversion Model: Conceptual Approach. *Journal of Transportation Engineering*, 119(4), 1993. pp. 515-534.
- Cragg, C. A., and M. J. Demetsky. *Simulation Analysis of Route Diversion Strategies for Freeway Incident Management. Final Report.* No. VTRC 95-R11. Virginia Transportation Research Council in Cooperation with the U. S. Department of Transportation Federal Highway Administration, 1995.
- Cuneo, D., M. Jha, & M. Ben-Akiva. *An Evaluation of Integrated Freeway Traffic Control and Route Diversion using Microscopic Simulation*. Massachusetts Institute of Technology, 1999.
- Lin, P. S., & C. C. Kou. *Is an Alternative Route More Effective During a Freeway Incident?*. Institute of Transportation Engineers Annual Meeting and Exhibit (Held in conjunction with ITE District 6 Annual Meeting), 2003.
- Carson, J. L. *Best Practices in Traffic Incident Management*. Texas Transportation Institute, The Texas A&M University System, 2010.
- Berrittella, M., A. Certa, M. Enea and P. Zito. *An Analytic Hierarchy Process for the Evaluation of Transport Policies to Reduce Climate Change Impacts*. Climate Change Modelling and Policy, 2007.
- Chu, T. C., & C. T. Tsao. *Ranking Fuzzy Numbers with an Area between the Centroid Point and Original Point*. Computers & Mathematics with Applications, 43(1), 2002. pp. 111-117.
- Indian Roads Congress. *Guidelines for capacity of urban roads in plain areas*. IRC-106, 1990.