

ALTERNATIVE ROUTE STRATEGY FOR EMERGENCY TRAFFIC MANAGEMENT BASED ON ITS: A CASE STUDY OF XI'AN MING CITY WALL

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Subject review

Emergency traffic management calls for integration of strategies covering advanced information collecting/disseminating fallibilities, and effective message broadcast system. Approximate "permanent" alternate routes combining intelligent transportation system measures could objectively play a vital role in supporting the category of specific congestion alleviation and incident management. This paper attempts to address a methodology of prioritizing such "permanent" alternate routes via major traffic generators/attractors for route guidance and traffic diversion strategies in the concerned local network. A scenario of emergency management and operation is demonstrated to discuss the collection of real-time traffic data, location and duration evaluation of incident, identification of alternative routes and congestion evocation integrated with ITS, using a mixed network near Xi'an Ming City Wall as a VISSIM example. Finally, types of diagrammatic route guiding signs are addressed with application samples.

Keywords: *alternative route, emergency management, guiding sign, ITS measure, traffic diversion, Xi'an Ming City Wall*

Strategija alternativnog pravca za interventno upravljanje prometom temeljena na ITS: Studija slučaja gradskih zidina Xi'an Minga

Pregledni članak

Interventno upravljanje prometom zahtijeva integraciju strategija koje obuhvaćaju napredno prikupljanje /sirenjenje informacija o pogreškama, i učinkovit sustav emitiranja poruka. Približni "stalni" alternativni pravci koji kombiniraju inteligentne mjere transportnog sustava mogli bi objektivno igrati važnu ulogu u podržavanju kategorije ublažavanja posebnog zagušenja i upravljanja incidentima. Ovaj rad pokušava riješiti metodologiju davanja prioriteta takvim "stalnim" alternativnim pravcima preko glavnih generatora / atraktora prometa za strategije navođenja i preusmjeravanja prometa u odgovarajućoj lokalnoj mreži. Demonstrira se scenarij interventnog upravljanja i rada kako bi se razmotrili prikupljeni stvarni podaci o prometu, procjeni mjesta i trajanja incidenta, identifikaciji alternativnih pravaca i uzroku zagušenja integrirani sa ITS (Inteligentnim Transportnim Sustavima), koristeći mješovitu mrežu blizu gradskih zidina Xi'an Minga kao VISSIM primjera. Konačno, razmatraju se vrste vodećih znakova dijagramske rute s uzorcima primjene.

Ključne riječi: *alternativni pravac, gradske zidine Xi'an Minga, interventno upravljanje, ITS mjera, preusmjeravanje prometa, vodeći znak*

1 Introduction

Recently, identifying the real-time road traffic conditions has been long considered as one of potential measures in alleviating the congestions, lengthening the queues, better utilizing the network capacity, and increasing the system performance via intelligent transportation systems (ITS) among the mixed roadway networks [1, 2]. Due to the rapid urbanization with population growth and vehicle expansion over the past decades, effective roadway system consisting of freeways, arterials, sub-arterials, branches and local streets, is commonly developed in an urban area to provide the daily travel service [3]. However, severe congestion frequently happens on freeways and certain arterials while other roads are lightly loaded, because no real time traffic message is guided for possible alternate routes. Obviously, such an unbalanced distribution of vehicle flow decreases the network capacity and operation efficiency [4].

For an individual driver, it is extremely useful that a route guidance system can provide the shortest or an alternative path during an incident condition. As a key component in ITS, advanced traveller information / management systems (ATIS/ATMS) assist drivers prescriptively in making more informed decisions on departure time, route choice, route diversion, and congestion avoidance [5]. In this way, they can be used by traffic controllers to reach traffic equilibrium and improve network efficiency by triggering favourable routes, or diversion suggestions, or both by users [6]. This indicates the need to understand the factors that influence drivers'

response to supplied route guidance information [7]. However, the implementation is really unrealizable [8], due to the difficulties in vast algorithm computations, consistent interaction between guiding messages and responsive behaviours, and lack of route signs, etc.

A variable message sign (VMS) control heuristic proposed by Peeta & Gedela focuses on dynamic route guidance through variable message sign based on driver behaviour in seeking diversion in incidents. The key element is used to identifying traffic states, enabling computational tractability by real time traffic data, and ensuring the spatial and temporal consistency of offline and online messages to be displayed, which is verified using data on VMS response survey from the Borman Expressway in Indiana and a simulator experiments [9].

However, the general ITS based route guidance system is not effectively available for every roadway segment. In the analysis of vehicle infrastructure integration (VII) initiative, individual VII-equipped vehicles are envisioned to play the role of supporting the operations of ATIS/ATMS, using real-time travel-time information and comparing various route guidance strategies under VII-enabled condition [10]. To a specific trip attractor (e.g. railway station, airport, hospital, commercial centre, etc.), there usually exist several alternate routes [11]. To determine these "permanent" links or nodes in determining alternate routes, important or vulnerable such locations should be identified at first, and the final decisions should explicitly account for the alternative routes' excess capacity, travel time and driver's personal favourites [12]. For isolated freeways, arterials and local streets could be used as connectors

between non crossed freeways and roadside guidance signs to provide sufficient diversion guidelines away from another congested route in case of severe incidents.

However, the real organization of diversion traffic is extremely difficult due to particular conflicts between buses, cars, motorbikes, three-wheelers, bicycles and pedestrians in Chinese cities [13]. Therefore, this paper attempts to build up a methodology to prioritize key links and nodes in the roadway network in Xi'an Ming City Wall area according to their individual "importance to the network". The paper then discusses the mechanism of a "permanent" route signing guidance system integrated with ATIS/ATMS for incident control and emergency management in a mixed network of Ming City Wall in Xi'an, in which special arterials, sub-arterials or local streets are used as connectors permanently between congested road segments. Finally, several types of alternate route guidance signs are briefly exhibited based on the practical implementation and literature review.

2 Traffic diversion strategy

2.1 Prioritizing corridors and key locations

A number of freeways, arterials and sub-arterials in current Xi'an city, have witnessed severe congestion problems among roadway network. Ming City Wall, for example, a region located in the middle region of Xi'an city, has 38 km² of area, about 60 signalized intersections surrounded by one major arterial, Huancheng Rd.

The Ming City Wall is a regional transportation hub and attracts numerous daily travellers from other districts including Qujiang, College City, Railway Station, North Railway Station, Xiaozhai, Xianyang International Airport, two major Medical hospitals –Maternal and Child Care Service Centre and Children Hospital, etc. Due to its importance in the 'heart' of Xi'an city, Ming City Wall is facing alarming challenges of traffic congestion, pollution, and emergence event response, and meanwhile, the area of Ming City Wall burdens very heavy daily traffic on major arterials and related streets.

To cope with these problems induced by heavy traffic, ITS solutions have long been recommended for this area. As part of ITS countermeasures, the route guidance is viewed as a key element to performing the city's ATIS/ATMS and bearing some cut-through traffic volume to relative light traffic roadways from various traffic generators/attractors or congested roads [14]. To determine alternate routes, key links and nodes related to overall network need to be prioritized by "importance to the network" that can be evaluated through: 1) operation performance, including safety, level of service (LOS), and traffic volume; 2) intelligent management (i. g., segment of signal coordination, VMS, camera or loop detector, etc.); 3) position [15].

Therefore, those links or nodes mostly stay at worse level of service or bear heavier traffic, and thus are usually judged as critical locations [16]. Let's assume that the performance evaluated from those critical locations can represent the critical status of overall network. Considering all above aspects and different user needs, the quantitative criteria with one uniform ranking feature is proposed to prioritize ITS field surveillance locations, as shown in Tab. 1, based on 1) annual average number of

crashes over the past 5 years (crash rate); 2) LOS of intersections; 3) annual average daily traffic volume (AADT); 4) traffic monitoring system including cameras, loop detectors, etc.; 5) dynamic route guidance system; 6) signal control pattern; 7) proximity to traffic generator (PTG); 8) proximity to freeways or arterials (PFA).

$$P_j = \sum_{i=1}^8 w_i f_i, \tag{1}$$

where, P_j is the priority ranking of detector type j ; f_i is the feature weight for criteria i ; and w_i is the importance weight assigned to criteria i .

Table 1 Prioritizing criteria of links and nodes

<i>i</i>	Criteria	Range	<i>f</i>	<i>w</i>
1	Crash rate	> 25	5	4
		15 ÷ 25	4	
		10 ÷ 15	3	
		5 ÷ 10	2	
		< 5	1	
2	LOS	F, E	5	4
		D	4	
		C	3	
		B	2	
		A	1	
3	AADT	> 50 000	5	3
		35 000 ÷ 50 000	4	
		20 000 ÷ 35 000	3	
		10 000 ÷ 20 000	2	
		< 10 000	1	
4	Monitoring system	Full sage	5	3
		Partial usage	3	
		No usage	0	
5	Route guidance system	Full sage	5	2
		Partial usage	3	
		No usage	0	
6	Control	ATC	5	2
		TDC	3	
		ITC	1	
7	PTG	Adjacent	5	1
		Not adjacent	0	
8	PFA	Adjacent	5	1
		Not adjacent	0	

Note: ITC = individual time based control;
 TOD = time of day control via computerized traffic management;
 ATC = adaptive traffic control with traffic responsive plan.

Based on the initialized locations of critical elements, corridors or intersections in the study area are ranked by Eq. (1) as principal, major and minor priority nodes or links with respect to $P = 80 \div 100$, $50 \div 80$, and $0 \div 50$, respectively. Usually arterial linking two or more regions (i. g., administration, residence, commerce & trade, sport & entertainment, transportation hub, etc.) and providing regional access is ranked the top, or termed principal priority corridor. Sub-arterial provides local access to commercial, industrial and residential areas and thus is ranked as major priority corridor that is secondary to the principal type. Moreover, minor priority corridor is mainly chosen among local branches and streets. Fig. 1 illustrates the law of selecting individual arterial, intersection via the weighted ranking importance P .

Importantly, the specific concerns and individual demands are derived from traffic engineers, planners, managers, projects consultants, and general users for

locating ITS elements [17]. Upon the viewpoint of rankings and survey, critical intersections are identified to install closed circuit television (CCTV) cameras, video/data detector, variable message signs, trailblazer signs, signal coordination devices, etc.

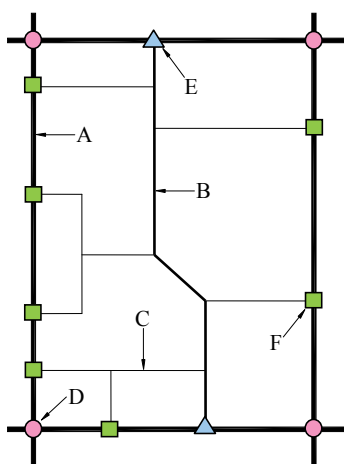


Figure 1 Importance of nodes and links: A) arterial; B) sub-arterial; C) branch and street; D) principle node; E) major node; F) minor node

2.2 Incident management scenario using alternate routes

Re-arranging the priority corridors and critical locations in Fig. 1, a regional ITS strategy is employed to monitor and guide the distribution of traffic flow among the roadway network of Ming City Wall. Geometrics, facilities, and environmental factors of individual road within this enclosed area are input into the Synchro software to simulate the traffic operation performance under the diverted traffic flow, supposing heavy congestion has appeared on priority corridor West Street caused by an incident occurrence [18]. Obviously, most segments as alternative routes are under level of service C and it indicates that those alternative routes have capacity to accommodate the diverted flows from regional arterials (West Street, South Street, North Street and Huancheng Road), sub-arterials and local streets.

Four steps procedure: When an incident occurs on a priority corridor, ATMS could help drivers find an alternative route and roadside VMS or TBS also guide the diversion [19]. It illustrates the procedure of emergency traffic management in a four-step fashion:

a. Real - time traffic data collection & processing. Traffic flow data (i.e., volume, occupancy, speed, density, etc.) are derived from installed cameras and detectors on a real-time basis;

b. Incident monitoring and detection. Traffic performance is dynamic evaluated by variables (v/c, level of service, capacity, etc.) and the presence or absence of capacity-reducing incidents is monitored through the change rate of certain traffic flow variables;

c. Alternative route choice. The current traffic state and congestion performance is assessed by the embedded algorithms so as to search for the alternative routes;

d. Alternative route guidance. Alternative routes are provided to drivers via VMS, TBS or broadcast in the route guidance system. The alternative signal control program is also performed for traffic diversion strategy.

Traffic monitoring: Traffic state is monitored continuously via the loop/camera detectors installed along the priority and major corridors. Field traffic data (speed, volume, occupancy and density) is received and processed every 30s for each travel lane.

A data processing server reports the real – time traffic in the format of speed, length of platoon queue, delay, level of service and capacity on a certain time interval, especially for signal-controlled junctions along arterials. Some missing, unreasonably high or low values will be specifically "smoothed". The processed data is stored in the incident detection subsystem and users also acquire the messages through data acquisition platform.

Fig. 1 shows the mean and standard deviation of travel time for the South Huancheng Road, a major corridor surrounding the Ming City Wall. Obviously, the free flow travel time is about 5 minutes during the period of 8:00 PM to 6:00 AM. There is a significant increase in the mean travel time during the morning and afternoon peak hours, and the standard deviation of travel time also increases, along with the increase of mean speed.

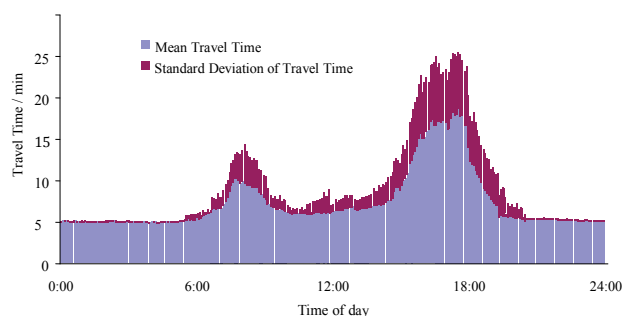


Figure 2 The mean and standard deviation of travel time of South Huancheng Road

Incident detection: The occurrence of incident is detected via the automatic incident detection algorithm embedded in ATMS, which monitors speed, volume and occupancy and identifies the incident through the change of these variables [20]. As shown in Fig. 3, traffic detectors are installed every 200 m along the segment and the occupancy *OCC* of traffic flow (%) is measured by

$$OCC = \frac{\sum_i (l_i + d) / u_i}{T} = \frac{1}{T} \sum_i \frac{l_i}{u_i} + \frac{d}{T} \sum_i \frac{1}{u_i} = \frac{1}{T} \sum_i \frac{l_i}{u_i}, \quad (2)$$

where l_i is the length of vehicle i (m), d is the length of detector (m), u_i is the traveling velocity of vehicle i (m/s), and T is the monitoring time (s).

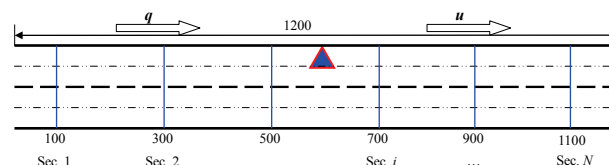


Figure 3 Real time traffic detectors installed along segments

If a particular detector and its downstream detector have detected abnormal or over-threshold changes beyond the AID standard, then it may be inferred that a potential incident has occurred somewhere between the upstream and downstream detectors. The California algorithm is

often used to detect the occurrence of incident between stations i and downstream station $i-1$ for the time interval t , using which depends on the increasing of occupancy (present) at station i upstream $OCC(i, t)$ and the decreasing of downstream occupancy $OCC(i, t)$ by Eq. (3) [20, 21].

$$OCCDF = OCC(i, t) - OCC(i+1, t) \geq K_1, \tag{3a}$$

$$OCCRDF = \frac{OCC(i, t) - OCC(i+1, t)}{OCC(i, t)} \geq K_2, \tag{3b}$$

$$DOCCTD = \frac{OCC(i+1, t-2) - OCC(i+1, t)}{OCC(i+1, t-2)} \geq K_3, \tag{3c}$$

where $OCCDF$ is the spatial difference in occupancies between station i and downstream station, $OCCRDF$ is the relative difference in occupancies between station i and downstream station, $DOCCTD$ is the relative temporal difference in downstream occupancy, and K_i ($i = 1, 2, 3$) is the critical value.

Traffic diversion and signal control strategy: Once an incident is verified, the feedback messages may guide drivers around the incident location to use other alternate routes. The flashing alarms and other roadside static directional signs are displayed to warn the vehicles of the occurrence of congestion. In the meantime, the incident location and influence areas are also highlighted onto the vehicle equipped GIS map, and the users could learn the details about the real time traffic conditions and choose the future alternative routes with light flow [22].

The traffic managers then remotely control the regional traffic through adjusting the signal control plans of certain involved intersections on a real-time basis to accommodate the diverting traffic demand from heavy traffic roadways to high LOS roadways. If necessary, police has the responsibility to provide guidance at the incident spot. As shown in Fig. 4, for example, a severe crash appears at South Huancheng Road and the effect of emergency crash is spread forward and backward beyond the intersection. For this principal priority corridor, the segment is almost congested. Then the data processing platform detects the abnormal change of traffic flow at the first time, using the derived data from installed CCTV cameras or automatic detectors. The corresponding message is also feedback to general control centre and the overall traffic condition is then assessed in time. Alternative routes are suggested and the decision messages are also sent back to the VMS.

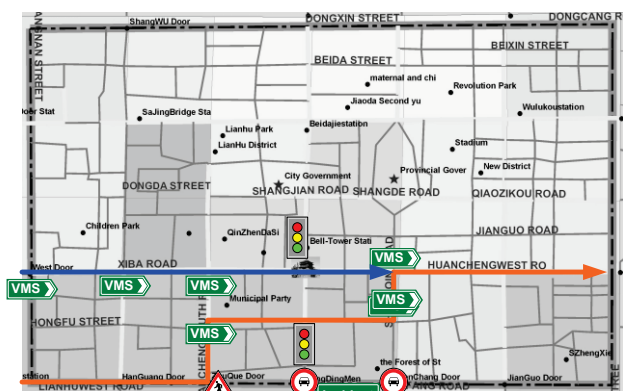


Figure 4 Traffic diversion in Ming City Wall

Similarly, traffic heading to the east area of Ming City Wall through South Huancheng Road could use an alternate route on a major or minor corridor to avoid incident related congestion occurring on that arterial. An example of this alternate routing is shown in Fig. 4. A static directional sign will help guide the drivers to follow the alternate route. A CCTV camera installed near incident location will allow the nearest operators in TMC monitor traffic status. Of course, simple guidance sign is also used to control passing through platoon flow during the period of minor incident (see Fig. 4).

2.3 Traffic guidance performance

To examine and understand the performance of alternative routing guidance strategy under congestion state, the experimental network of Fig. 4 in Xi'an Ming City Wall is constructed in VISSIM including three unsignalized intersections and seven signalized intersections as shown in Fig. 5. Tab. 2 presents the traffic flow of each OD pair within this study region.

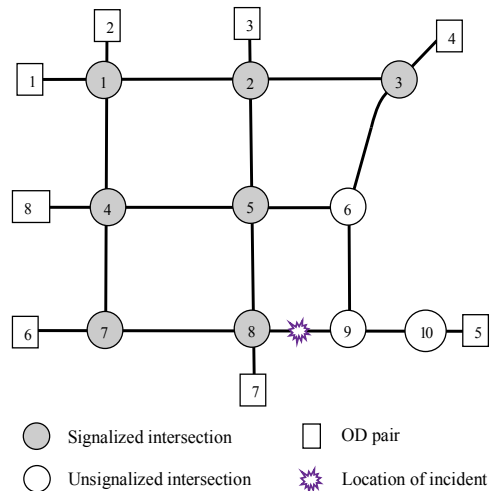


Figure 5 Experimental road network and OD pair

Table 2 Traffic flow between OD pair (pcu/d)

	1	2	3	4	5	6	7	8
1	0	196	116	177	0	71	45	56
2	52	0	15	8	1	14	0	15
3	235	1	0	65	77	180	142	17
4	261	2	30	0	63	49	28	12
5	0	0	11	23	0	257	135	3
6	76	5	139	120	103	28	268	29
7	10	0	237	165	6	167	0	22
8	0	0	23	18	6	22	34	0

Let's suppose an incident occurs at a line segment connecting two intersections of 8 and 9 that is about 250 m away from intersection 9. For simplification, here we assume that the incident causes the close of two lanes in one direction and thus one lane of another direction is temporarily used. Obviously, this incident causes congestion with queues and delays of vehicles on some segments, especially those related to intersections 8 and 9, and thus more vehicles involved in congestion need to be provided the guiding helps to alternative routes.

Here, five guidance strategies are performed including: 1) No guidance; 2) 100 % guidance that means

all the vehicles involved in the congested segment; 3) Gradual guidance with an increasing step of 5 % per 100 s; 4) Dynamic guidance; 5) K shortest path with real-time message broadcast, in the VISSIM parameter choice. The simulation experiment lasts 3600 s, in which the first 900 s is to reach the balance of traffic flow and the incident occurs at 901 s. Here, private car accounts for 62 %, bus 13 %, taxi 11 %, pick-up truck 9 % and motorcycle 5 % in traffic flow, according to the survey. Then the different types of traffic flow are transferred in the passenger car unit (pcu) by (source: Technical Standard of Highway Engineering, JTG B01-2003):

$$f_{HV} = \frac{1}{1 + \sum P_i (E_i - 1)}, \quad (4)$$

where P_i is the percentage of type i flow, and E_i is the passenger car equivalents of type i flow.

Subsequently, the performance of each guiding strategy under congestion state is checked for the test network in Fig. 5 and Tab. 3 presents the cost of each guiding strategy that is measured in the travel time, in which the total cost = $\sum T_j$, and the mean cost = $\sum T_j / N$, where T_j is the travel time of vehicle j in the test area, and N is the total number of vehicles measured in pcu. Obviously, the K shortest path guiding strategy achieves the best performance with the least systemic cost and average cost, which also proves that VMS helps guide vehicles into evacuation routes [23].

Table 3 Benefits of traffic guiding strategies

Cost	No guidance	100 % guidance	Gradual guidance	Dynamic guidance	K shortest path
Total /1000 s	44 861	44 167	39 142	33 279	32 134
Mean / s·pcu-1	8587	8455	7493	6370	6151

3 Route Guiding Signs

There are various types of alternative route guiding signs, such as freeway and arterial connector guidance, route information system guidance, alternate route mileage information sign, and dynamic alternate route guidance signs, etc., installed at multiple-lane segments, exclusive turning lanes, upstream and downstream intersections, freeway ramps, and all of them provide navigational messages for diverting travellers [24].

Route information guidance sign is a common used type of static guiding signs aiming at presenting the real time graphic traffic performance (v/c) of segments and intersections as well as the usual guiding information. The RIG signs indicate the traffic state by means of light points that may appear in green, yellow and red marks representing free, light and heavy traffic states.

The dynamic alternate route guidance sign presents the congestion level graphically on the through route as well as any alternate ones with higher level of service that is used to manage special planned or emergency traffic. Obviously, the dynamic route guiding service depends on the real time traffic information collection, decision making and operations surveillance [25]. If a detector identifies an incident, the item is transferred to the traffic information centre where the severity and influence of

induced congestion are to be simulated and evaluated immediately. The alternative routes are also suggested with signing alarms serving the event venue.

Fig. 6 presents the Europe's largest dynamic route guidance system used in Nuremberg, Germany (Source: http://en.wikipedia.org/wiki/Variable-message_sign). The dynamic sign installed provides the real time traffic messages (i. g. travelling speed, incident influence, maintenance activities, etc.), alerts drivers to emergency incident ahead and suggests an alternative route.



Figure 6 Dynamic route guidance system in Nuremberg, Germany.

4 Conclusion

Transportation system is a significant and vital part of a regional infrastructure, and needs to be a critical component of any regional emergency management program. A comprehensive regional ITS based signing alternate route guidance system for traffic diversion strategies helps to ensure compatibility between subsystems and sharing of data between appropriate institutions. This paper presents a practical method to identify key nodes or links (i.e., specific intersections, large traffic generators/attractors, etc.) that are important to the network and to provide a roadmap for system deployment and integration. The ITS based signing route guidance system is also specifically addressed: real time traffic data are collected, assimilated and distributed in an integrated manner, incidents as well as alternative routes are detected and evaluated by embedded algorithms, and then route guiding messages are provided via emergency management techniques. An experimental example by VISSIM verifies that dynamic alternative route guidance techniques help maximize the evacuation efficiency of congestion routes. Finally, the authors attempt to summarize types of alternate route guidance infrastructures supporting and enhancing ITS functionality with illustration of application examples.

Further research will focus on how the transportation system could be utilized in the event of a major

emergency incident or disaster. For example, one-way traffic for emergency vehicles from the crash location to the nearest hospitals could be established, in the event of a severe traffic crash at one of the arterials. How best to utilize the surface fastest response route depending on the level of traffic congestion scenarios, as well as the ITS infrastructure that is in place for the emergency traffic management including setting traffic control, road flares, and requesting emergency and towing services, should be thoroughly discussed and strategies developed. Currently, the various emergency response agencies operate their radios on their own frequencies and it will strongly require a combination of strategies.

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