GIS coupled with traffic simulation and optimization for incident response

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Abstract

Incident response measures are continuously being developed to deal with each incident in an effective and timely manner. One critical component in incident response actions is to deploy appropriate response units to the incident scene and clear the incidence as quickly as possible. This paper presents a novel approach for dispatching response units, which incorporates an optimization process for multiple incident response management. An incident response management tool (IRMT) has been developed by integrating Geographic Information System (GIS) with traffic simulation and optimization engines. GIS is employed to provide the primary user interface, process network data, derive the shortest-time path, and visualize the results. The traffic simulation engine is used to simulate incidents in a network, gather link travel times at regular intervals and transmit this time dependent information to GIS. Finally, the optimization engine is used to derive an optimal dispatching strategy by minimizing the total travel time of all the response units. Upon comparison with conventional strategies based on location proximity, the IRMT is found to considerably reduce response time and facilitate resource optimization.

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Keywords: GIS; Incident management; Incident response; Traffic simulation; Optimization; Vehicle dispatching

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1. Introduction

Traffic incidents occurring in urban areas have been recognized as a major cause for road congestion delays. This has long been a serious problem confronting both social communities and individuals. It is estimated that such incidents roughly account for 50–60% of the total traffic congestion in urban transportation (FHWA, 2000), and apparently the negative effects of these incidents might not subside in the near future. Motivated by this fact, there is a clear need to pay considerable attention to reduce such delays through efficient incident response. One way of improving the incident response efficiency is to promptly dispatch appropriate response units to the incident scene. In doing so, it can be ensured that fatality and occurrence of secondary incidents are minimized. To address this need, this paper focuses on devising an optimal dispatching strategy with the aid of various information technologies, including Geographic Information Systems (GIS).

Over the past decades, GIS have been increasingly used as an efficient tool for a wide range of applications such as emergency response and transportation planning and management. GIS has evolved beyond the initial stages of data management and mapping, and have advanced into spheres such as modeling and analysis thus facilitating spatial decision making. Several attempts have been made to integrate different models into GIS and combine GIS with the development of Intelligent Transportation System (ITS). Such an amalgamation is inevitable to meet the increasing demand on enhancing GIS functionalities in solving transportation problems, e.g. incident response management. Along with the closer integration of GIS and transportation, there has been a rapid growing field of “GIS-T” (GIS for Transportation) (Fletcher, 2000; Goodchild, 2000; Miller & Shaw, 2001; Thill, 2000).

Albeit GIS have demonstrated their capabilities in spatial data manipulation and analysis in a variety of transportation related problems, they are found to be inadequate in dynamic spatial analysis within GIS-T. One vital component in incident response actions is, however, to use dynamic traffic information for deploying appropriate response units to the incident scene. Obviously this would necessitate tremendous resources in collecting real-time traffic information. In the absence of such real-time traffic data through video cameras or sensors, simulation data have proved to be a convenient and cost effective alternative (Cheu & Ma, 2001; Li, Huang, & Pan, 2003). Traffic simulation, due to its ability to capture the full dynamics of time dependent traffic phenomena, has become a popular tool for examining the feasibility and assessing the impact of a transportation planning design. As a result, the integration of GIS with traffic simulation systems offers an ideal environment for devising and testing incident response strategies.

Devising an incident response strategy also involves the allocation of incident response units such as tow trucks, fire engines, and police cars. Incidents of different severity may need different number of response units. For instance, some incidents may need only one response unit for efficient response, while others may need several more. Another aspect that is involved is the minimization of total travel time in response to probably multiple incidents. While these require optimization support, GIS itself is not able to fit this requirement. A feasible solution is to equip GIS with an optimization engine which is capable of performing mathematical programming such as linear, nonlinear, and quadratic programming (Huang, Cheu, & Liew, 2004). Consequently, the integration of GIS with both traffic simulation and optimization is required for incident response management.
This paper develops a method for deriving an optimal response strategy by combining GIS, traffic simulation, and optimization techniques. To examine the applicability of the method, an incident response management tool, IRMT, has been developed. This incident response management tool utilizes TransCAD GIS, PARAMICS traffic simulation system, and the LINDO optimization tool. The strategy devised by this tool is illustrated by comparing it with the conventional strategy which only considers location proximity without optimization, and it is demonstrated that the proposed strategy outperforms the conventional strategy.

The remainder of this paper is organized as follows. The following section provides a literature review on incident management. Then, the proposed IRMT tool is introduced, which includes its framework, optimization model and user interface. Subsequently, the application of the proposed methodology is demonstrated through a case study. Finally, a summary is provided and possible future work is discussed.

2. Related work

Incident management (IM) refers to the coordination of activities undertaken by one or more agencies to restore traffic flow to normal conditions after an occurrence of incident. Incident management is already being considered and treated as an integral part of freeway traffic operations (Ozbay & Kachroo, 1999). The process of incident management consists of several major steps: incident detection, incident verification, response formulation and dispatching, clearance of incident, and post-incident traffic recovery (FHWA, 1998; Giuliano, 1989). Incident detection and verification are the determination of the occurrence of an incident and the type and location of the incident, respectively. Incident response management concerns the activation, coordination, and management of appropriate personnel and equipment to clear the incident. The major goals of incident clearance and recovery are to restore normal traffic flow conditions in a safe and time-efficient manner after responding to the incident appropriately. A well designed and efficient incident management operation can reduce the cost incurred by the incident in terms of delay, wasted fuel, and even the economic loss.

Intelligent Transportation Systems (ITS) play a central role in incident management (Ozbay & Kachroo, 1999). Examples of ITS technologies for emergency management include incident detection, computer aided dispatching, and traffic signal preemption for emergency vehicles, which offer faster, safer, and more efficient tools for incident management. FHWA (1998) summarized and interpreted findings from the ITS Field Operational Test (FOT) projects in the field of incident management. For instance, Advance Driver and Vehicle Advisory Navigation Concept (ADVANCE) utilized vehicles as exploratory aids for monitoring traffic conditions on freeways and arterials in a large geographic area (incident detection), and provide diversionary routing to vehicles carrying the onboard vehicle navigation unit (traffic recovery). However, a great deal of the current ITS technologies are being utilized in detection, verification, and motorist information, whereas they are scarcely applied to incident response strategies, though it is also an essential part in incident management.

Of late, the application of GIS to transportation planning and management has been receiving substantial attention. GIS allow users to integrate a variety of transportation data, such as incidents, pavement conditions, and sign inventories, and relates those data to a particular point or road segment in a spatial referencing system. The key technique of
these applications is network analysis, whose primary focus has been the shortest-path problem. The development of an efficient incident response strategy requires a valid shortest path finding method that is able to cope with the dynamic traffic network information.

Several studies have been carried out on applying GIS for incident management, such as transportation hazard analysis in an integrated GIS environment (Huang et al., 2004; Lepofsky & Abkowits, 1993), development of a wide-area incident management support system (WAIMSS) (Ozbay & Kachroo, 1999) and hazardous materials transportation management (Panwhar, Anderson, & Pitt, 2000). Clearly, the ability of a GIS in managing spatially referenced information offers an edge for transportation management operations. In time critical operations such as incident response, information pertaining to network condition should be up-to-date as this influences the decision making process significantly. However, GIS itself cannot provide time dependent traffic information. In this research, the GIS network analysis function is improved to integrate the time dependent traffic information supplied from a traffic simulation system.

Traffic simulation systems have recently evolved into a powerful tool to meet the requirement of transportation design and analysis for their noticeable ability in real transportation system representation, re-constructing, evaluation and even on-line control strategy operation. These are attributed to their well-developed theoretical foundations and advancement of computer technologies. In transportation studies, it would cost tremendous resources in field experiments, especially in collecting enormous traffic information for incident management. However, traffic simulation has proven to be a convenient and cost effective approach for providing real-time traffic information in support of incident detection and incident analysis (Jeng, 2003; Qi, 2003).

In general, simulation is defined as the dynamic representation of some part or process of the real world achieved by building a computer model and moving it through time (Drew, 1968). Traffic simulation systems can be divided into several different types. One of the basic classifications is the division between macroscopic, mesoscopic and microscopic models, according to the level of detail with which they represent the system to be studied (Edward & Rathi, 1998). Traffic simulation models can be classified as either microscopic, mesoscopic, or macroscopic. Microscopic models predict the state of individual vehicles either continuously or in a discrete manner. While macroscopic models provide a comprehensive description of the traffic flow conditions, microscopic measures point to individual vehicle speeds and locations. Mesoscopic models are models that include the combined aspects of both macro and microscopic models. Thus, it can be seen that macroscopic models can only represent entities and their activities or interactions with low fidelity. Even though the mesoscopic model with mixed fidelity shows entities at a relatively high level than the macroscopic one, it is still at a much lower level in describing their activities and interactions as compared to microscopic model. Among the different types of traffic simulation tools mentioned above, microscopic simulation tools are found to be the most suitable for simulating real traffic conditions and testing control strategies.

Very little has been reported when it comes to vehicle dispatching optimization (e.g. incident response unit). The only work that is relevant to this paper was undertaken in the area of Emergency Medical Service (EMS) dispatching (Haghani, Hu, & Tian, 2003). An optimization model for real time emergency dispatching and routing was proposed which considered en route diversion and reassignment. However, in EMS dispatching, the required incident response time (time to reach the call location) is usually no more than 5 min in the urban area (FHWA, 1998). Therefore, even though vehicle reassignment
(on the way to an incident) may be useful in theory for optimizing the network total response time, we may also argue that in a real situation it is not necessary to reassign the vehicle in such a short time. For example, even if it could reduce 10% time from the reassignment strategy, the exact time that could be saved is no more than 30 s. Thus, this kind of time length is not considered significant as compared to the time cost of drivers’ rerouting behavior. Nonetheless, if there are any block links caused by serious traffic congestion on the route, the rerouting process may still be needed. Besides, the most serious incidents must be dealt first, especially when the response resources are inadequate. Another consideration is that of a situation wherein an incident might necessitate more than one vehicle to respond. These issues have been addressed using a concrete implementation within a GIS environment in our study.

3. The incident response management tool – IRMT

3.1. Framework of IRMT

As shown in Fig. 1, a novel framework for incident response management has been formulated in this research, which links the incident response management optimization model (IRMOM), the LINDO optimization engine, the PARAMICS microscopic traffic simulation tool with the TransCAD GIS.

In this study, we employ TransCAD, probably the only GIS designed for use by transportation professionals to store, display, manage, and analyze transportation data (Caliper, 2001a, 2001b), as the principal GIS platform. Its built-in GISDK macro script is employed to develop an IRMT, which brings together the time dependent travel information generated by the microscopic traffic simulation tool, the LINDO optimization engine, and TransCAD to implement the IRMOM and create support strategies for incident response unit dispatching.

PARAMICS is a suite of high performance software tools used to model the movement and behavior of individual vehicles on urban and highway road networks (Quadstone, 2000). This tool functions as a generator of dynamic link travel time in IRMT.

LINDO is one of the leading linear programming optimization software developed by LINDO Systems, Inc. (Lindo, 2002). The LINDO optimization engine provides applica-
tion programming interfaces (API) for user customizations. We employ this tool to resolve the optimal assignment problems of response units and output the results into TransCAD GIS for further analysis and presentation.

We utilize loose coupling as well as tight coupling to integrate the three sub-systems. Loose coupling relies on the transfer of data between the GIS and other systems, while tight coupling requires a unified data structure and user interface. PARAMICS simulation tool has its own data model, data structure, graphics rendering, and display schemes, which are independent of the GIS tool. Huge effort is needed to achieve a tight coupling of these two tools. Hence a loose coupling approach is more convenient for linking GIS and the simulation tool through common datasets. Unlike PARAMICS with TransCAD, the LINDO optimization engine is tightly coupled with TransCAD. TransCAD has an efficient and powerful function to call external executable (.EXE) file and DLLs to assist its internal GIS functions. As a result, the incident response management optimization processor, which embeds the LINDO DLLs, is tightly linked with TransCAD to resolve the resource optimization problem.

3.2. Incident response management optimization model (IRMOM)

There are several types of response units (RUs) which are used in daily incident management operations (e.g. fire trucks, ambulances, tow trucks, and patrol cars). In this case, tow trucks are selected as a general proxy of the response units. In this research, incidents are categorized into four priorities, namely high (fourth-level), medium (third-level), low (second-level) and negligible (first-level), respectively. Each level of incident may need a different number of response units, e.g. an incident with high level priority requires two RUs (see Table 1).

3.2.1. Model formulation

A two-phase incident response management optimization model (IRMOM) is developed to (i) maximize the total weights of severities of the incidents to be dealt with under currently available response resources and (ii) to minimize the total response travel time of all the tow trucks. The two-phase IRMOM is formulated as follows:

Phase 1:

*The objective function:*

\[
\max \sum_{j=1}^{N_i} a_{S(j)} z_j
\]  

(1a)

<table>
<thead>
<tr>
<th>RUs needed for incidents with different priority</th>
<th>High (fourth-level)</th>
<th>Medium (third-level)</th>
<th>Low (second-level)</th>
<th>Negligible (first-level)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incidents with different priority</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RUs needed</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
Constraint set:

\[
\sum_{i=1}^{N_i} x_{ij} \geq b_{S(j)}z_j, \quad \forall j \in N_i \tag{1b}
\]

\[
\sum_{j=1}^{N_i} x_{ij} \leq 1, \quad \forall i \in RU^1 \tag{1c}
\]

\[
x_{ij} = 0 \text{ or } 1, \quad \forall i \in RU^1, \forall j \in N_i \tag{1d}
\]

\[
z_j = 0 \text{ or } 1, \quad \forall j \in N_i \tag{1e}
\]

Phase 2:

The objective function:

\[
\min \sum_{i=1}^{N_i} \sum_{j=1}^{N_i} x_{ij}t_{ij}(t) + \sum_{i=1}^{N_i} \sum_{j=1}^{N_p} y_{ik}t_{ik}(t) \tag{2a}
\]

Constraint set:

\[
\sum_{i=1}^{N_i} x_{ij} \geq b_{S(j)}z_j, \quad \forall j \in N_i \tag{2b}
\]

\[
\sum_{j=1}^{N_i} x_{ij} \leq 1, \quad \forall i \in RU^1 \tag{2c}
\]

\[
\sum_{k=1}^{N_p} y_{ik} = 1, \quad \forall i \in RU^2 \tag{2d}
\]

\[
x_{ij} = 0 \text{ or } 1, \quad \forall i \in RU^1, \forall j \in N_i \tag{2e}
\]

\[
y_{ik} = 0 \text{ or } 1, \quad \forall i \in RU^2, \forall k \in N_p \tag{2f}
\]

Input variables

- \(t_{ij}(t)\) travel time of shortest path between points \(i\) and \(j\) at time step \(t\)
- \(t_{ik}(t)\) travel time of shortest path between points \(i\) and \(k\) at time step \(t\)
- \(S(j)\) the function that returns the priority of a given incident \(j\)
- \(a_l\) the weight of severity of incidents with \(l\)th priority
- \(b_l\) the number of tow trucks needed to be dispatched to an incident with \(l\)th priority
- \(N_i\) the number of incidents that are waiting for tow trucks
- \(N_t\) the number of tow trucks
- \(N_p\) the number of car parks (parking lots where the break down vehicles can be put)
- \(RU\) the set of tow trucks in the whole system
- \(RU^1\) the subset of the available tow trucks that move on the road network
- \(RU^2\) the subset of the tow trucks which are ready to leave for car parks upon completion of tasks at incident locations
Note: RU$^1$ and RU$^2$ are mutually exclusive.

Decision variables

\[ z_j = 1 \] if the \( j \)th incident will be treated by certain tow trucks, otherwise 0

\[ x_{ij} = 1 \] if tow truck \( i \) is dispatched to the incident \( j \), otherwise 0

\[ y_{ik} = 1 \] if tow truck \( i \) is leaving for car park \( k \), otherwise 0

In phase 1 of the model, the objective function (1a) is to maximize the total weights of severities of incidents to be treated while not exceeding the number limitation of available tow trucks. Constraint (1b) ensures that sufficient number of tow trucks be dispatched to each incident location. Constraint (1c) indicates that one tow truck can only serve only a single incident at any given time. Constraints (1d) and (1e) represent integer constraints.

The second phase of the model serves to minimize the total estimated travel time of the tow trucks that are required to move from their current locations to the assigned incident locations, and those that have completed their site operations at the incident locations and are ready to tow away the affected vehicles. Constraints (2b) and (2c) are the same as constraints (1b) and (1c), respectively. Constraint (2d) ensures that the tow truck be assigned to only one car park upon completion of its task at the incident location. Constraints (2e) and (2f) are the integer constraints.

3.2.2. Model analysis and implementation

In phase 2 of the above model, the subsets RU$^1$ and RU$^2$ are mutually exclusive; hence, the second phase of the model can be decomposed into two separate mathematical sub-models. These two models are those that deal with the response units in RU$^1$ and RU$^2$, respectively. The two sub-models are described as follows:

**Sub-model 2.1 (Derive the optimal response strategy of response units in RU$^1$).**

The objective function:

\[
\min \sum_{i=1}^{N_1} \sum_{j=1}^{N_i} x_{ij} t_{ij}(t) \tag{3a}
\]

Constraint set:

\[
\sum_{i=1}^{N_1} x_{ij} \geq b_{S(j)} z_j, \quad \forall j \in N_i \tag{3b}
\]

\[
\sum_{j=1}^{N_i} x_{ij} \leq 1, \quad \forall i \in RU^1 \tag{3c}
\]

\[
x_{ij} = 0 \text{ or } 1, \quad \forall i \in RU^1, \forall j \in N_i \tag{3d}
\]

**Sub-model 2.2 (Derive the optimal response strategy of response units in RU$^2$).**

The objective function:

\[
\min \sum_{i=1}^{N_1} \sum_{j=1}^{N_p} y_{ik} t_{ik}(t) \tag{4a}
\]
Constraint set:

\[
\sum_{k=1}^{N_p} y_{ik} = 1, \quad \forall i \in RU^2
\]  

\[
y_{ik} = 0 \text{ or } 1, \quad \forall i \in RU^2, \quad \forall k \in N_p
\]  

All the variables have the same meaning as defined above. The decomposed models can help develop a software tool to facilitate decision making. Logically, the tool should consist of two parts that deal with the two sub-models, respectively. As such, the solution process should be more efficient.

The above Integer Linear Programming (ILP) models (both the phase 1 and phase 2 models) are implemented inside TransCAD which calls the incident response management optimization processor coded within LINDO.

3.3. The IRMT interface

The IRMT is a window-based tool developed using the built-in macro script of TransCAD. It is composed of two main tabs, namely Tab of Response Units to Incidents and Tab of Response Units to Car Parks, which correspond to the two aforementioned sub-models. IRMT provides a user friendly interface (Fig. 2) through which users can easily trace an incident location associated with its priority and occurrence time. Additionally, users will also be able to update relevant link travel times, generate the optimal response strategy and obtain the textual and visual results.

3.3.1. Choice Tab of Response Units to Incidents

The Tab of Response Units to Incidents (termed as Tab A later) is a functional panel (as shown in Fig. 3) with two push buttons. The first button is Incident Information Button (termed as Button 1 later) dealing with the input and incident information management. The second button is the Response Strategy Button (termed as Button 2 later), which triggers the optimization engine and uses the simulated dynamic traffic information to derive the optimal response strategy for operation and control of response units.

3.3.1.1. Incident information. When Button 1 is clicked upon the occurrence of an incident, a window (Fig. 3) pops up, through which users can input the incident information, e.g. incident occurrence time, priority and location, and manage the incident database. A three
A multi-dimensional array is then used to store the incident data that is automatically created and refreshed upon each run of IRMT.

3.3.1.2. Acquisition of Response Strategy. When all the incident information, including occurrence location, time and priority, has been entered into the incident database, users may click on the button of Response Strategy. This triggers the window of Response Strategy (Fig. 4) to obtain the optimal response strategy based on the real-time traffic information generated by PARAMICS. After the final step, a message box pops up to report the best response strategy, e.g. RU 2 to INCI (1) and RU 4 to INCI (1). The corresponding routes recommended for each RU are highlighted on the map.

For purposes of demonstration, a certain number of RUs (e.g. 5) are randomly generated among the whole road network when users click on the button of Information of RU. The location data of RUs is simultaneously transferred to the IRMT from the GPS devices within the RUs through the convenient access provided by TransCAD.

3.3.2. Choice Tab of Response Units to Car Parks

The Tab of Response Units to Car Parks (termed as Tab B later) is similar to Tab A in its layout, with two buttons (see Fig. 5). The first button (termed as Button B1, Incident
Information button, is used for inputting data related to incidents where RUs have completed site assistance and are ready to tow the affected vehicles to car parks. The second one (termed as Button B2), namely the Car Park Direction, gives the optimal path for those ready-to-go RUs from the incident sites to car parks.

4. Case study

We tested and evaluated the proposed IRMT using a suburban road network in the Clementi area of Singapore. The testing of the IRMT prototype begins with the network coding in both PARAMICS and TransCAD.

4.1. Study area and network coding

4.1.1. Network coding in PARAMICS

Fig. 6 shows the road network of Clementi area coded in PARAMICS. It is noted that the parameters of the PARAMICS model considering local traffic characteristics in Singapore was already recalibrated by Qi (2003). The PARAMICS based microscopic simulation has been found to be an efficient means for instantaneous traffic information simulation and analysis (Ma, 2003).

The entire network was coded based on the traffic information provided by the Land Transport Authority (LTA) of Singapore. This network included nine main arterials, 22 secondary roads, and an expressway with four interchanges. The network consisted of 986 links, 397 nodes and 22 Original Destination (OD) zones in PARAMICS. Within the network there were 34 signalized intersections. With the phase plans provided by the LTA, actual signal control procedure was coded for all the intersections in the simulated network. The signals in the network were coordinated with fixed offsets. Based on the overall traffic demand, the cycle time varied between 60 s and 140 s. In PARAMICS, the hourly input volume was specified in an Origin–Destination (OD) matrix. As discussed in Ma (2003), the hourly distribution of overall traffic flow pattern was derived based on the partial link volume provided by LTA.

4.1.2. Network coding in TransCAD

The study network was digitized in TransCAD based on the scanned larger scale Street Directory map, which was set to follow the corresponding Coordinate System for Singapore. This setting ensured that the accuracy of the digital map was maintained for subsequent operations. The general view of the network in TransCAD is illustrated in Fig. 7.
Fig. 6. Road network coded in PARAMICS.

Fig. 7. Road network coded in TransCAD.
The network elements in the study included two components, namely, Clementi Network line layer and accessional Endpoints point layer. However, to completely satisfy the special traffic condition of the real network, some additional parameters were included. First, the “Display Themes and Intersection Diagrams” option under the Preferences dialog of the Edit menu should be changed into “Drive on Left”. This is essential as Singapore adopts the right hand drive mode. Then all the one-way links were edited by using the Link Direction option under the Networks/Paths menu. Besides, the useful turn penalty information was stored in a Turn Penalty Table through the Turn Penalty Toolbox option under the Networks/Paths menu. All these modifications assure the consistency between the digital map and the real network, and even the coded PARAMICS network.

4.2. Link database between TransCAD and PARAMICS

Dynamic routing based on the travel time updated at regular time intervals is an important function in IRMT. However, the link definitions and the data structures between TransCAD and PARAMICS are different. For example, link I, link II, link III and link IV in PARAMICS represent route 1 in TransCAD (see Fig. 8). Hence, a link database was constructed to facilitate the data transfer between PARAMICS and TransCAD. Fig. 9 shows some parts of the link database used in the case study. In addition to the dynamic link travel time that can be obtained directly by simulation, the incidents loca-

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Fig. 8. Link representations in PARAMICS and TransCAD.

Fig. 9. Link database connecting TransCAD with PARAMICS.
tions and some other useful traffic data simulated in PARAMICS can also be accessed using the macro script in the TransCAD environment through the link database.

4.3. Experiment results and analysis

4.3.1. Representation of incident

In this case study, three incidents with different severity levels occurring in the road network were considered. Table 2 shows the details of all the incidents in the case study. The red points and incident information dialog box in Fig. 10 display the incident information in TransCAD. Five tow trucks were available and they are moving around the road network. Seven car parks (points with blue parking marked in Fig. 10\(^1\)) were identified as possible destinations for the tow trucks to tow the affected vehicles.

---

Table 2

<table>
<thead>
<tr>
<th>Incident</th>
<th>Occurring time</th>
<th>Location</th>
<th>Incident type</th>
<th>Duration time (min)</th>
<th>Priority</th>
<th>Number of tow trucks needed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>09:58</td>
<td>Arterial road</td>
<td>Vehicle break down</td>
<td>12</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>10:00</td>
<td>Expressway</td>
<td>Two car accident</td>
<td>30</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>10:10</td>
<td>Arterial road</td>
<td>Vehicle break down</td>
<td>10</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

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\(^1\) For interpretation of color in this figure, the reader is referred to the web version of this article.
4.3.2. Determination of the optimal incident response strategy

The proposed approach was tested on the study area under four different scenarios (see Table 3) where incidents occurred at different time steps. Scenario 1 presented two incidents (Incidents 1 and 2). Three tow trucks were assigned to the incident locations at time step S1. In scenario 2, there were three incidents in the whole network, in which one incident (Incident 3 in Table 2) was waiting for response from a tow truck; the second one was handled by two response units at the incident scene and for the third incident, the tow truck coupled with the break-down vehicle was leaving for the appropriate car park. In scenario 3, there were two tow trucks waiting at specific points to deal with incidents and another one was leaving for a car park. For scenario 4, except for those idle ones, the other tow trucks were leaving for car parks after clearing up the incident scenes.

4.3.3. Results and analysis

The proposed dispatching model was compared with the conventional dispatching approach, which allocates the tow trucks based on the shortest distance to the incident location. The conventional approach was confirmed to be the one that uses locational proximity to dispatch response units after interviewing the related officers and engineers several times.

The two approaches were both implemented in a PC with a Pentium 1.6 GHz CPU and 256 MB RAM running on a Windows XP system. The results of the comparison are shown in Table 4. It is found that the proposed approach outperforms the conventional strategy. In scenarios 1 and 2, the proposed approach saves up to 45% and 10% of the total travel time, respectively. In scenarios 3 and 4, the two approaches achieve similar performance while solely considering the travel time from the incident scene to the car park.

### Table 3
The number of tow trucks at each scenario

<table>
<thead>
<tr>
<th>Test</th>
<th>Scenario</th>
<th>Moving to incident locations</th>
<th>Staying in incident scenes</th>
<th>Leaving for car parks</th>
<th>Available number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>S1 (10:00:00)</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>S2 (10:10:00)</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>S3 (10:20:00)</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>S4 (10:30:00)</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

*Note: Total tow truck number is five.*

### Table 4
Differences of the total travel time between the proposed approach and the conventional dispatching strategy (case 1)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Proposed approach (s)</th>
<th>Common strategy (s)</th>
<th>Time reduced (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Part I</td>
<td>Part II</td>
<td>Total</td>
</tr>
<tr>
<td>1</td>
<td>608.00</td>
<td>NA</td>
<td>608.00</td>
</tr>
<tr>
<td>2</td>
<td>141.70</td>
<td>217.70</td>
<td>359.40</td>
</tr>
<tr>
<td>3</td>
<td>NA</td>
<td>155.44</td>
<td>155.44</td>
</tr>
<tr>
<td>4</td>
<td>NA</td>
<td>66.07</td>
<td>66.07</td>
</tr>
</tbody>
</table>

*Notes: (a) Part I – total travel time of all tow trucks that are assigned to the incidents locations; (b) Part II – total travel time of all tow trucks that are leaving for the car parks; (c) NA – not applicable.*
To further verify the efficiency of the proposed approach under different traffic conditions, three incidents with severity levels similar to the previous case (Table 4) were considered. Their occurrence times were, however, different from the preceding case and their corresponding locations were randomly generated using macro script. In comparison with the conventional strategy, the proposed approach was found to reduce about 10% and 25% of the total travel time in scenarios 3 and 4, respectively (see Table 5).

The remarkable improvement achieved by the proposed dispatching model demonstrates that this approach is indeed an effective way in incident management operations.

5. Conclusion

This paper illustrated a method for deriving an optimal dispatching strategy for incident response by integrating GIS, traffic simulation, and optimization systems. In this method, the optimization model minimizes the total travel time of all the response units while maximizing the total levels of severities of the incidents to be dealt with given under current available response resources. The traffic simulation tool generates the dynamic traffic information which is then fed into the GIS and the optimization model. In addition to verifying the effectiveness of the proposed method, our case study also verifies the efficacy of the associated tool. When compared with the conventional dispatching strategy, considerable enhancement was achieved when using the proposed methodology.

The methodology proposed in this research can assist incident management centers/traffic engineers in optimally dispatching response units. Notably, the case studies illustrate that a GIS furnished with dynamic traffic information and optimization engine offers a powerful platform for intelligent incident response management and presents a promising research area requiring further exploration.

While the proposed approach has demonstrated an important step towards improvement on incident response management, there is still room for improving this approach. For example, this approach could be implemented using a large road network in an American or European city. However, in order to do this, the corresponding traffic information of the large area (e.g. OD matrix and travel time on the critical links and junctions) must be available in the future. Clearly the proposed approach and IRMT can be significantly enhanced with more tests using different networks. In addition, while tow trucks have been used as an example of response units, the proposed strategy could be extended to many other types of response units. These could be RUs that are used in daily incident management operations, such as fire engines, ambulances, and patrol cars, etc. and concurrently

<table>
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<th>Common strategy (s)</th>
<th>Time reduced (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Part I</td>
<td>Part II</td>
<td>Total</td>
</tr>
<tr>
<td>1</td>
<td>613.32</td>
<td>NA</td>
<td>613.32</td>
</tr>
<tr>
<td>2</td>
<td>397.78</td>
<td>171.10</td>
<td>568.88</td>
</tr>
<tr>
<td>3</td>
<td>NA</td>
<td>100.51</td>
<td>100.51</td>
</tr>
<tr>
<td>4</td>
<td>NA</td>
<td>373.87</td>
<td>373.87</td>
</tr>
</tbody>
</table>

Notes: (a) Part I – total travel time of all tow trucks that are assigned to the incidents locations; (b) Part II – total travel time of all tow trucks that are leaving for the car parks; (c) NA – not applicable.
an integration of different types of response units (e.g., fire engines and tow trucks) in incident management could also be investigated.

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References