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Analysis of freeway service patrol with discrete event-based simulation

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ABSTRACT

As an efficient incident management program, freeway service patrol has gained wide popularity. There is increasing need for developing systematic procedures of planning the program to ensure efficient resource allocation and to achieve maximum benefits. A discrete event-based simulation model is developed to replicate the patrol process that includes districting, incident generation, response vehicle dispatching and routing, and incident clearance. Model validation proves its capability to accurately replicate the incident generation/distribution process. Later, the Interstate-95 freeway in south Florida is used as a model application example to test alternatives, and the improved alternative shows better performance compared with the previous even-length districting method and the currently used even-activity districting approach. Besides traditional roving scheme, the simulation model also has the capability to evaluate the prepositioning schemes. Furthermore, sensitivity analysis is performed to examine the impact of operational parameter settings, such as beat districting, incident detection rate, and incident frequency. Although continuous efforts are needed to develop a more comprehensive simulation model for the freeway service patrol program, the application example presented in this study reveals promising application results, and provides an insight into the patrol process as well as a better understanding of the impact of parameters on performance.

1. Introduction

Non-recurrent congestion on freeway is mainly caused by incident, and contributes to a large part of traffic delay. Incidents cause excess fuel consumption as well as air pollution as reported by Lindley [1], also result in secondary accidents by Zhan et al. [2]. Besides, Red Cross report [3] shows that 57% of all victims who are killed die in the first minute after the crash, before the arrival of the emergency services. Effective incident detection and verification, response, and clearance are essential to improve safety and traffic conditions. The attention of the US government has been directed toward effective freeway incident management strategies, such as the use of freeway service patrol (FSP), automatic incident detection, and closed circuit television (CCTV) camera, to reduce the impacts of incidents. Kaas's [4] review indicates that many evaluation studies of FSP have reported high benefit-cost ratio.

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The FSP is a complex process with random inputs, and the operational parameters of a patrol program, such as size of patrol area, fleet size, hours of operations, and response vehicle depot locations, influence the required time of response vehicles to reach the incident location. For the evaluation of a patrol program, it is necessary to develop simulation models that can reproduce the patrol process as completely as possible. Given the infrequency feature of incidents under a daily time frame, the developed model should be operated on a year basis in order to capture the random pattern of incident distribution, which brings another requirement of time efficiency to the simulation model. This paper reports a phase output of an ongoing effort toward developing a systematic procedure for FSP that is a discrete event-based simulation model with the capability of replicating the patrol process including districting, incident generation, response vehicle dispatching and routing, and incident clearance.

2. Previous research work

Freeway incident response, as a subarea of emergency response, has been a hot topic in the operation research community. Most studies focused on the development of methodological framework to reduce incident duration by optimizing the number of emergency vehicles, response policies, routing schemes, and relevant jurisdiction areas. In general, methodologies used in previous work can be summarized into two groups: analytical method and simulation method.

Zografos et al. [5] first proposed an analytical framework with linear programming technique that can minimize the freeway incident delays through the optimum deployment of traffic flow restoration units. Pal and Sinha [6] constructed a mixed integer programming model to determine optimal locations for response vehicles, given the frequencies of incidents at potential sites in the network, which could minimize the annual cost, but the determination was subject to the fleet size constraint. An opportunity cost-based model proposed by Sherali and Subramanian [7] demonstrates that dispatching the closest available vehicle to the site of the current accident is not always the optimal incident response strategy when considering the expected future demands. A simple analytical method was proposed by Khattak et al. [8] to determine the most beneficial locations for patrol deployment by combining crash rate, congestion level, estimation of incident-induced delay, and estimated B/C ratio of FSP. However, this method did not tackle the specific patrol process. Yin [9] developed a min–max bi-level programming model to decide the allocation of FSP. Later, he also [10] proposed a mixed-integer nonlinear programming model to allocate FSP vehicles by minimizing the expected loss associated with incident occurrence.

Recognizing the highly stochastic nature of the incident management operations, researchers started to apply simulation to solve the problem. Developed by Nathanail and Zografos [11], the first tool applied Poisson distribution to the occurrence of incidents, whereas uniform distribution is assumed for incident spatial distribution. Incident duration for lane-blockage incidents (incident occurred on travel lane) was extracted from archived data, while the duration for shoulder incidents (incident occurred on shoulder) was based on empirical judgments. Zografos et al. [12] presented a decision-support system for incident management decision-making by integrating mathematical models, rules, and algorithms in a user-friendly environment to minimize incident response time. Pal and Sinha [13] also developed a simulation tool for the selection of FSP operational parameters. The traffic flow was modeled at a macroscopic level mainly based on queuing theory to calculate incident delays and determine diversion assumptions. However, the prepositioning scheme was not modeled.

In a paper by Ozbay and Bartin [14], a simulation tool was developed with Arena simulation package. This study focused on testing the impact of the incident detection methods. Results showed that in failing to detect the incident, it would take a maximum of 20 min for the responsible agencies to be informed by other means (cell phones). Haghani et al. [15] developed a simulation model to evaluate a real-time emergency medical service system, which dealt with general emergency response problems. However, freeway service patrol has its special characteristics, such as different incident types, change of travel duration with time, and work load balance problem. Recently, to assess the impact of the parameters on service patrol operations, Hadi et al. [16] developed a simulation tool that was proven to have the capability to accurately replicate the incident generation/distribution, the travel duration change with time and the patrol process. Unfortunately, as the initial stage of their work, the pre-positioning schemes and influences of patrol conditions are not investigated.

As demonstrated in the literature review, for the evaluation of a patrol program, the latest studies tend to focus on developing simulation models that can reproduce the patrol process. However, very few studies have been conducted to develop systematic planning or evaluation procedures of those programs. This paper is a continuation of the work by Hadi et al. [16] and initiated by the Florida Department of Transportation (FDOT) District 4 through investigating many patrol policies including the pre-positioning schemes and testing various patrol parameter settings to further understand the patrol process and assess the program. The following part of this paper first describes the need for a simulation model, the current FDOT practice, and the data in the sample application. Afterwards, the simulation model is illustrated, and the sample application of the model with the Interstate-95 incident data is summarized. At the end, some conclusions and future work are presented.

3. Need for a simulation model

Freeway patrol vehicles respond to incidents on the freeway as quickly as possible to provide emergency aid and relieve the impact on congestion. The traditional roving strategy of FSP program can be summarized as: response vehicles patrol within the assigned beat and watch for any incidents; upon detection of an incident, the vehicle reaches the incident location