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# Simulation-based evaluation of evacuation effectiveness using driving behavior sensitivity analysis

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ABSTRACT

Worldwide, man-made or natural phenomena occasionally occur that create emergency conditions and require the evacuation of areas of different sizes and characteristics. Drivers' behavior becomes a very important factor for the evacuation operations. This paper provides an analytical study of the effectiveness of evacuation according to drivers' behavior, using the sensitivity analysis method. Collecting real-time data about this factor is a difficult to impossible task for large scale cases; therefore, traffic simulation is the most appropriate method for analysis. Our goal is to investigate how drivers' aggressiveness affects the evacuation effectiveness. In this case, we used the AIMSUN traffic simulation model; the parameters of the driver behavior models are chosen through all-at-once sensitivity analysis of the parameters. This model is applied to different demand scenarios for well-defined parameters' value ranges. This investigation produces estimated ranges of the evacuation duration and the number of evacuated people, both for a baseline "do-nothing" scenario, as well as the outcome of improvement actions. The sensitivity analysis results suggest that evacuation time can be significantly reduced by reversing the most congested links; furthermore, the use of a bus fleet would allow many more people to evacuate the danger zone timely, albeit with a small increase in minimum evacuation time. This methodology could be applicable to other emergency response scenarios, as it obviates the need for real-time data.



## 1. Introduction

Natural and man-made disasters threaten essentially all parts of the world. Some areas, such as islands, pose additional constraints. For example, in this research, we consider the case study of the evacuation of the Greek island of Santorini, due to a natural disaster that is related to the active volcano of this area, such as an earthquake or even the explosion of the volcano [25]. While there are many approaches in developing and optimizing the response strategies to an emergency, simulation-based approaches have attracted a lot of attention during the last decade. Emergency response planning has several specific differences from general simulation studies. One such difference relates to the lack of reliable data from emergency situations. Therefore, other strategies are needed, in order to develop the simulation study and create the response strategies.

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In this research, the lack of real-time data about the drivers' behavior leads to the application of sensitivity analysis of the key model parameters, in order to identify those parameters that affect the results the most and use them for the case study. A systematic way to select the parameter values for the sensitivity analysis is required. In this research, these values are selected randomly within the specified limits, depending on the levels of analysis that are carried out and all the possible combinations of parameter values. Moreover, a minimum number of iterations is defined for each parameters' set that is necessary in order to normalize the result and avoid the randomness of a particular simulation execution.

The remainder of this paper is structured as follows. In Section 2, a literature review of the state-of-the-art is presented. Section 3 outlines the methodology that was developed and used for the analysis of the study. Section 4 presents the case study setup, while Section 5 presents the results that were obtained from this study. Section 6 discusses the findings of the study, followed by a final concluding section.

## 2. Literature review

Natural or man-made disasters, such as typhoons [13], earthquakes [23], flooding [19] fire [17] or industrial accidents [31] may affect populated areas and endanger human lives. It is, therefore, necessary to evacuate the affected areas and move the population in safe areas. The evacuation planning is often supported by modern tools, such as evacuation models, which allow the evaluation of parameters such as the evacuation time and the safest routes that lead to safe zones. Depending on the mode selected in response to evacuation incidents, the corresponding technique is utilized as evacuation by traffic management, route planning, based on the start time, or on driver behavior.

The approach of traffic management through simulation performs a representation of journeys through stochastic models using simulation tools such as Aimsun [4], DynaMIT [5], TransModeler [6], etc. These models are based on the configuration of demand as a result of the Origin-Destination matrices. Moreover, there are models such as CLEAR [Loudoun County, Office of Evacuation Management], NetSim [21], which combine a set of computer programs in order to calculate the evacuation time and create evacuation plans of an area under different parameters, such as weather conditions or time of day. [3] developed a model that predicts and evaluates traffic conditions for use under an emergency, which was applied to the evacuation of the central area of the city of Boston. Several models have been presented in order to define the existing conditions when the volume of demand is at its maximum, and thus to calculate the time required to evacuate the danger zone [18]. While most studies operate at the route level, there are studies that have focused on traffic management per lane by calculating the network flows and indicating the optimal routes for each lane [10].

The route planning approach turns the evacuation problem into a traffic management problem, as it assumes the definition of planned origin-destination routes. Thus, the evacuation design is essentially reduced to finding the optimal route (optimal mathematical solution) for each individual flow of the network using e.g. route selection algorithms and linear programming methods [30]. A technique used a lot in route and evacuation planning applications is the use of Geographic Information Systems (GIS). Through these systems, not only are the definition of evacuation routes and the size of the affected population facilitated, but also can their spatial interaction be analyzed, leading to useful estimations [24]. The evacuation based on the start time is preferred when the evacuation area is strongly urban, with high population density, in order to benefit of the optimal use of the network capacity, without creating intense congestion [33]. On the other hand, dynamic traffic management models allow the design based on drivers' behavior and the evaluation of traffic impact [8].

Furthermore, the simulation is one of the few methodologies that allow the analysis of the parameters or modifications that have not been implemented yet [1]. It is obvious that, thanks to the ability to take into account the human factor, traffic simulation can be used to design, develop and evaluate advanced traffic information systems (ATIS) [11].

As to the design parameters, a number of approaches have been developed, depending on the case examined in each study. Thus, the more detailed the illustration of the network is, the easier it becomes to design the evacuation planning and the use of microscopic simulation tools that utilize especially such data [10]. For example, some parts of the network may be destroyed by some natural disaster (e.g. landslide) or may not be accessible from a moment onwards due to an accident [26]. Furthermore, the choice of areas that will serve as safe zones can be accomplished by various methods of monitoring the wider area, as aerial photos or satellite observations, in situ observation in the field or using analytical maps of the specific characteristics of the area [28]. Sometimes, for computational reasons, the safe zones are concentrated in a uniform area defined by a centroid [7]. Even in the event of increased demand or due to a phenomenon that blocks a part of the evacuation network, the use of contraflow lanes is often proposed, to accelerate the evacuation [14,15,34].

Thankfully, emergency situations are fortunately relatively few and far apart. Therefore, even if it was possible to collect data from single emergencies, it would be hard to use them to plan our response to future similar emergencies, as they would undoubtedly be somewhat different (e.g. somewhat different location, somewhat different magnitude/severity, different season, day in the week and time of day, i.e. demand patterns). Therefore, a single evacuation response plan would not be necessarily optimal or suited to the precise situation at hand. One way to deal with this uncertainty is through sensitivity analysis. Sensitivity analysis is the study of how the uncertainty of the result of a mathematical model or system (numeric or not) can be allocated to different sources of uncertainty of data [29]. One of the simplest and most common approaches is the change of a factor at a time (one-at-a-time, OAT), to determine how this affects the result [22]. However, the OAT approach cannot detect the presence of interactions between the input variables, as it does not take into account