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Evacuation modeling including traveler information and compliance behavior

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Abstract

Traffic simulation models are often used to support decisions when planning an evacuation. Scenario analyses based on these models then typically focus on traffic dynamics and the effect of traffic control measures in order to locate possible bottlenecks and predict evacuation times. A clear approach to incorporate traveler information and compliance behavior in evacuation modeling is however lacking. The consequence is that the impacts hereof are often insufficiently accounted for. In this contribution, we show how traveler information and compliance behavior are included in the evacuation model EVAQ by applying a hybrid route choice model and internalizing the generalized costs of deviating from the instructions. The impact of traveler information and compliance behavior is discussed using a case study describing the evacuation of the Rotterdam metropolitan area in the Netherlands.

Keywords: Compliance; information; instructions; evacuation modeling

1. Introduction

Many natural and man-made disasters can be anticipated on, for instance, bush fires, hurricanes, floods, terrorist attacks, and industrial accidents. This implies that, up to a certain level, we can predict that such a disaster may occur and may affect a certain region in a certain manner. A most probable disaster scenario can then be used to plan the best way of avoiding or mitigating the effects of the disaster, for instance by planning an evacuation. The success of an evacuation strongly depends on many factors, such as warning time, response time, information and instructions dissemination procedure, evacuation routes, traffic flow conditions, dynamic traffic management measures, etc. Due to the complexity of the underlying processes and the multitude of factors influencing these processes, model-based approaches are required for the analysis and planning of emergency evacuations. The model can be applied to obtain a better understanding of the evacuation conditions and the effect of traffic regulations and control measures hereon, by predicting departure and arrival patterns, travel times, average speeds, queue lengths,

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traffic flow rates, etc. Insight into this dynamic process is necessary to make founded decisions on, for instance, the latest possible time to start evacuation, the best evacuation routes, or the most suitable traffic management measures.

A multitude of dynamic models have been developed and used to forecast evacuation conditions on a road network. A large number of these studies are conducted using traffic models originally developed for regular day-to-day traffic applications. For example, microscopic simulation models such as PARAMICS, CORSIM, and VISSIM were used for evacuation scenario analyses in [1]–[3] and for evaluating the impact of control measures, such as staged evacuations in [4] and contraflow operations in [5], [6]. In a number of these studies, model parameters describing driving behavior, such as headway, acceleration, and reaction time, are adjusted for the case of emergency evacuation. In other studies, evacuation is recognized as a special case regarding different travel demand patterns, driver behavior, traffic management, etc., resulting in new models dedicated to evacuation. For example, microscopic models, such as IMDAS [7], OREMS [8], and CEMPS [9], and macroscopic models, such as DYNEV [10], MASSVAC [11], and TEDSS [12], have been developed and used in the past decades.

Since the late 1970s, some of these models were developed to analyze and evaluate emergency evacuation plans. Early studies in the 1980s focused mainly on evacuation in case of nuclear power plant emergency due to the Three Mile Island reactor incident in 1979. Then, after a number of extremely devastating hurricanes hitting the coast line of the U.S. in the 1990s and in the past years, much evacuation research shifted focus to hurricane evacuation. Since the September 11, 2001, incident in the U.S., also mass evacuation due to terrorist attacks is getting more attention. Due to tsunamis in China and bush fires in Australia over the past years, evacuation research in these countries focus on these types of evacuation. For the Dutch situation, rising sea levels and increasing threat of flooding has led to the start of the Dutch national TMO (Taskforce Management Flooding) program, initiating flood evacuation research and applications within the Netherlands.

Traffic simulation models used in past evacuation studies generally focus on traffic flow dynamics to identify possible bottlenecks and compute expected evacuation times. As a consequence, a number of aspects relating to traveler behavior under evacuation conditions are insufficiently incorporated in the scenario analyses when applying these models [13]. In this contribution, we show how travel behavior relating to departure time and route choice under uncertainty (traveler information) and instructions (compliance behavior) can be modeled, and what the impacts are in terms of the model outcomes. We start by explaining how traveler information and compliance are incorporated in the evacuation model EVAQ in the next section. Thereafter, we use the case study of Rotterdam to discuss the impact of traveler information and compliance behavior. First, the research approach is presented, including the case setting and experimental set-up. Then, the numerical results are presented and elaborated on. In the final section, we conclude that aspects of traveler information and compliance may strongly dictate traffic states and evacuation times in a non-linear manner, and thus should be included in future research and evacuation model applications.

2. Modeling approach

The following is based on how traveler information and compliance behavior is modeled by the evacuation model EVAQ [14]. EVAQ is a model to predict traffic flow conditions on a road network for a wide range of emergency situations, such as hurricanes, bush fires and floods. Compared to other evacuation traffic models, the distinguishing features of EVAQ are: i) modeling of dynamic road infrastructure, ii) incorporation of adaptive traveler choice behavior, and iii) incorporation of evacuation instructions and traveler compliance behavior. The first advantageous feature of EVAQ is that it models time-dependent road infrastructure. Characteristics such as speed limits, capacity and flow direction can be time-varying due to the hazard's progress in space and time (e.g., links becoming inaccessible due to flooding) and prevailing traffic regulations and control measures (e.g., contraflow operations to increase outbound capacity). Capturing these important changes in the road infrastructure over time makes the model (outcomes) more realistic. Also, this feature enables simulating an acute evacuation in which network degradation plays a major role in the evacuation process. To realistically model the impact of time-varying road infrastructure, travelers need to be able to update their route at the next decision point whenever traffic conditions change (drastically) due to changes in the network. This route-updating behavior occurs in case of evacuation-related dynamic traffic management measures and hazard-inflicted network degradation. The same route-updating behavior is reasonable to assume in case travelers face uncertain traffic conditions and receive