EVAQ: An Evacuation Model for Travel Behavior and Traffic Flow

Adam J. Pel, Michiel C.J. Bliemer, Serge P. Hoogendoorn

Transport and Planning Department

Delft University of Technology, Stevinweg 1, Delft, the Netherlands

Email: a.j.pel@tudelft.nl

1 Context and Problem Description

Traffic simulation models are helpful or even indispensable while planning or managing an evacuation. A multitude of dynamic traffic models have been developed to this end to understand and predict evacuation conditions on a road network, and the effect of traffic regulations and control measures hereon. In many earlier 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 (e.g., OREMS [1], CEMPS [2], DYNEV [3], MASSVAC/TEDSS [4]). More recently, a large number of evacuation studies are conducted using traffic models originally developed for regular day-to-day traffic applications, including both microscopic models (e.g., PARAMICS, CORSIM, VISSIM) and macroscopic models (e.g., DYNASMART, DynaMIT, VISTA, CONTRAM). In several studies using microscopic models, model parameters describing driving behavior (headway, acceleration, reaction time) have been adjusted for the case of emergency evacuation.

These models used in past evacuation studies typically focus on traffic flow dynamics to identify bottlenecks where congestion is likely to occur and compute expected evacuation times. They do so by using a dynamic traffic assignment (DTA) model describing travel behavior and traffic flow. In spite of advances in evacuation modeling research, main shortcomings remaining in DTA models used for evacuation studies relate to (i) *route choice behavior* (user-equilibrium assumptions, invalidly disregarding travelers' unfamiliarity with evacuation traffic conditions), (ii) *compliance behavior* (actual travel decisions are modeled equal to instructed departure times, destinations and routes, invalidly disregarding travelers' preferences and compliance decisions), and (iii) *network dynamics* (road infrastructure is static, invalidly disregarding the impact of DTM measures and road network disruption due to the hazard). These essential aspects are typically neglected in current evacuation models, and hence in the scenario analyses when applying these simulation models. The consequences are 1) unreliable and likely wrong model outcomes and 2) being unable to, e.g., evaluate the impact of variations in traveler compliance, or test robustness of an evacuation strategy towards uncertain hazard conditions. In this paper, we propose the new DTA model EVAQ specifically tailored to the case of evacuation thereby solving the abovementioned shortcomings. The EVAQ model is described and applied to a large-scale case study of the evacuation of the Dutch metropolitan area of Rotterdam.

2 Evacuation Model Framework

The evacuation model EVAQ predicts travel behavior and traffic 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 advantageous distinguishing features of EVAQ are: (i) modeling of dynamic road infrastructure, (ii) incorporation of adaptive route choice behavior towards network dynamics and travel information, and (iii) incorporation of evacuation instructions and traveler compliance behavior. EVAQ models time-dependent road infrastructure, meaning that 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 regulation and control measures (e.g., contraflow operations to increase outbound capacity). While other models typically relate time-varying road infrastructure only to an impact in traffic flow propagation (e.g., lower speeds results in drivers experiencing higher travel times), in EVAQ this also affects en-route travel choice behavior (e.g., lower speeds leads to drivers adapting their routes at the next intersection). This same rerouting behavior is expressed when travelers receive new information on current traffic conditions. Both pre-trip and en-route route choice behavior are thus modeled by implementing a hybrid route choice model [5]. Traveler compliance towards instructions regarding departure time, destination and route is modeled by internalizing the generalized costs of deviating from these evacuation instructions, where these generalized costs are a function of the difference between the *preferred* travel decision and the

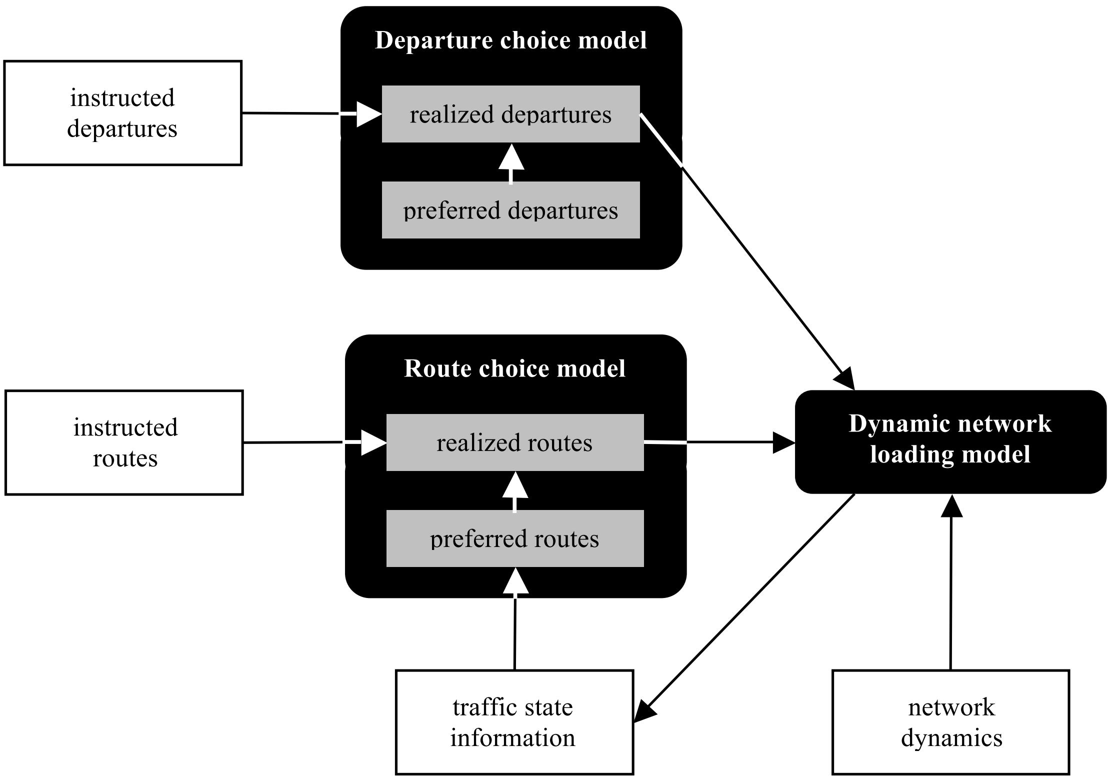

Figure 1: DTA components of EVAQ

instructed travel decision. A parameter is introduced dictating the relative weight of this cost term representing the travelers' willingness to comply and the authorities' enforcement to control. This way, subtle and behaviorally sound thresholds are built into the traveler choice model components allowing the researcher to analyze the impact of variations in traveler information and compliance behavior [6].

The model framework is depicted in Figure 1, showing the three model components for departure time decisions, route decisions, and traffic flow, and the three model inputs relating to instructions, information, and network dynamics (affected by the hazard). In the paper, we give a mathematical formulation of the model components modeling travelers' decisions regarding departure time and route (implying destination), and elaborate on how we incorporate the impact of travel information and instructions on these decisions. Subsequently, we present the traffic flow component simulating the traffic conditions, and show how network dynamics due to traffic control and network disruptions are modeled.

3 Model Application

To illustrate the scalability and potential of EVAQ, the model is applied to a case study describing the evacuation of the Dutch metropolitan area of Rotterdam (see Figure 2). With a population exceeding 600,000 inhabitants, the municipality forms the second largest in the country. The road network used in this study consists of the Rotterdam ring road, motorways connected to this ring road, main (provincial and urban) arterials, and collector roads, leading to approximately 500 links and 220 nodes, including 80 origins. EVAQ is implemented in Matlab. In case of applying a time step of 20 seconds in the traffic simulation model and simulating a time horizon of 48 hours, the CPU running time on a Windows XP computer with 2.2 GHz processor ranges from 10 to 20 minutes.

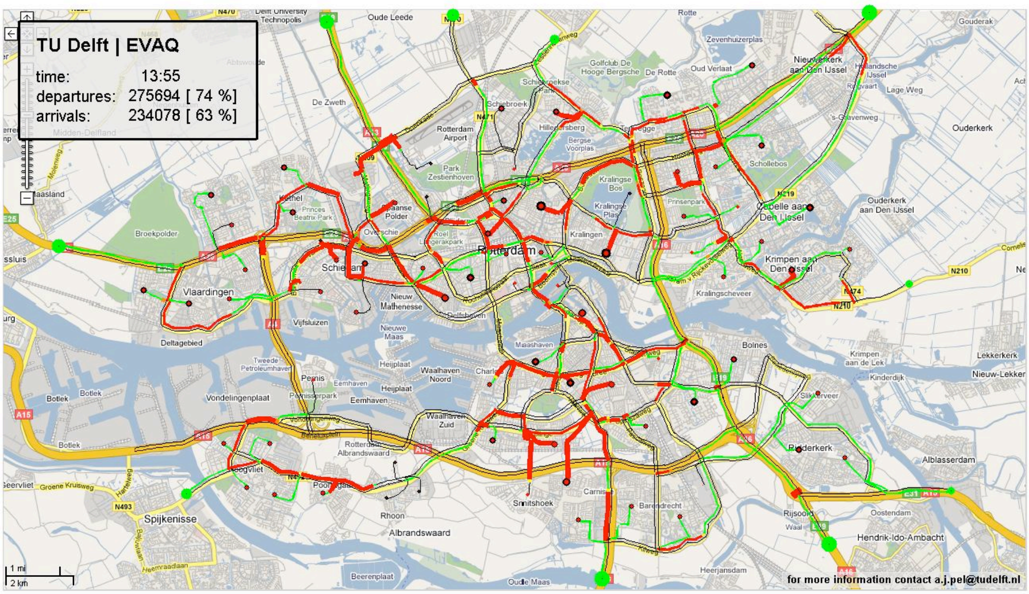

Figure 2: Rotterdam evacuation network

Rotterdam being a large harbor city, evacuation due to flooding, industrial accidents, or terrorist threats can be considered conceivable. Multiple simulations have been run varying in possible network exit points, traffic information levels, evacuation instructions, traveler compliance behavior, and network dynamics. These behavioral and control settings determine dynamic travel demands and route flow rates, and thus traffic states and network outflow utilization, where these relationships are shown to be (in some cases highly) non-linear and non-monotonic. Network clearance times for the different settings vary from 24 to 48 hours. More on the evacuation study can be found in [6].

EVAQ outputs link inflow and outflow rates, departure and arrival patterns, travel times, average speeds, queue lengths, etc. This dynamic information can be used to make founded decisions on, e.g., the latest possible time to start evacuation, the best evacuation routes, the impact of traffic information and evacuation instruction provision including compliance behavior, the most suitable dynamic traffic control measures, etc.

4 Discussion

This contribution presents the evacuation DTA model EVAQ, dealing with several shortcomings of current evacuation models, as mentioned above. The model framework is discussed and each of the components is described, as well as the manner in which these interact. The scalability and potential of EVAQ is illustrated by a real-life application describing the evacuation of the Dutch municipality of Rotterdam. In conclusion, the model framework and formulation, case results, discussion and conclusions presented in the paper can be used 1) to give direction to further research along this line on incorporating traveler choice behavior, compliance behavior, and network dynamics in evacuation simulation models, and 2) to understand the role of these aspects in the evacuation process and their assessment in evacuation planning studies.

References

[1] A.K. Rathi and R.S. Solanki, "Simulation of Traffic Flow during Emergency Evacuation: A Microcomputer based Modeling System", 25th Winter Simulation Conference, Los Angeles, CA, December 1993.

[2] M. Pidd, F.N. de Silva and R. Eglese, "CEMPS: A Configurable Evacuation Management and Planning System – A Progress Report", 25th Winter Simulation Conference, Los Angeles, CA, December 1993.

[3] KLD: "Formulations of the DYNEV and I-DYNEV Traffic Simulation Models used in ESF", Technical report prepared for the Federal Emergency Management Agency, KLD Associates, Inc., 1984.

[4] H.D. Sherali, T.B. Carter and A.G. Hobeika, "A Location-Allocation Model and Algorithm for Evacuation Planning under Hurricane/Flood Conditions", *Transportation Research Part B*, 25(6), pp 439-452, 1991.

[5] A.J. Pel, M.C.J. Bliemer and S.P. Hoogendoorn, "Hybrid Route Choice Modeling in Dynamic Traffic Assignment", *Transportation Research Record*, 2091, pp 100-107, 2009.

[6] A.J. Pel, S.P. Hoogendoorn and M.C.J. Bliemer, "Evacuation Modeling including Traveler Information and Compliance Behavior", 1st International Conference on Evacuation Modeling and Management (ICEM), The Hague, September 2009.