Evacuation Plan of the City of Almere: Simulating the Impact of Driving Behavior on Evacuation Clearance Time

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Abstract

The evacuation clearance time is one of the key indicators in an evacuation plan and is determined by the expected behavior of the endangered residents and roadway network characteristics. The city of Almere has developed an evacuation plan in case of the emergency of a flooding, but assumes a normal driving behavior of the evacuees. In this paper a microscopic S-Paramics simulation framework in an evacuation condition is set up to assess the impact of variations in driving behavior on the evacuation clearance time. Different scenarios in terms of acceleration rate, maximum speed, mean headway and minimum gap distance have been developed. The results show that increases in acceleration rate and in maximum speed do not have a significant impact on the evacuation clearance time. It is also found that a reduction both in mean headway and in minimum gap significantly reduce the evacuation time. Therefore, it is very important to consider the driving behavior in an evacuation condition for an evacuation plan.

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Evacuation time, Driving behavior, Minimum Gap, Mean Headway

1. Introduction

Natural disasters such as hurricanes, floods, big storms, and bushfires have caused massive damages as well as loss of life. For example, the North Sea flood of 1953 and the associated storm created a major natural disaster which affected the coastlines of the Netherlands and England on February 1st 1953. In the Netherlands 1835 people were killed. In the Netherlands, it is the task of the provincial safety department (‘Veiligheidsbureau’) to prepare evacuation plans and take appropriate (precautionary) measures related to the possible threat of flooding [1]. Part of this task is the setup of a traffic evacuation plan for each individual municipality during an evacuation. All of these individual plans will then be integrated into a province-wide traffic evacuation plan for the entire province.

One of the key indicators of the performance of the traffic evacuation plan is the evacuation clearance time, which is determined by the number of residents to be evacuated, the expected behavior of those residents, and roadway network characteristics [2]. When the evacuation clearance time rises, the endangered residents are at greater risk of death or injuries. With longer evacuation clearance times, either less people can be evacuated within a...
certain time frame or the evacuation order must be given earlier. However, when evacuation orders are given early and the flooding does not occur, the public becomes increasingly skeptical of the validity of the orders, which may affect the response during the next order. Therefore, a good estimation of the evacuation clearance time is critical to the safety of the public and serves to indicate the potential for extreme conditions. The traffic evacuation plan of the city of Almere has defined how the people should and will be evacuated in case of an emergency situation. The plan has been developed on logical reasoning, without the use of a traffic model. In this plan the capacity on the urban roads is estimated at 1200 vehicles per hour per lane. Given the assumed amount of traffic demand, the complete evacuation was estimated to be realized within approximately 19 hours, not taking into account the time that is necessary for moving road blockages.

This traffic evacuation plan assumed that the driving behaviors for evacuees are ‘normal’ – under the normal traffic conditions. Traffic flows under evacuation conditions however, are the result of the behavior of the endangered residents. That is how they respond to each other (e.g. minimum gap, headways etc.) under evacuation conditions. Drivers may behave more hasty or anxious during emergency conditions, causing their driving behavior to change drastically [3]. Therefore, we need to account for how the endangered residents may behave differently compared to the driving behavior under the normal traffic conditions. The different driving behavior may impact on the evacuation clearance time. To provide more insight in this issue, this paper proposes a Paramics Microscopic simulation based framework to evaluate the effects of changes in driving behavior on evacuation clearance time. The parameters of driving behavior like acceleration rate, maximum speed, minimum gap distance and mean headway are included in this framework. The remainder of this paper outlines the traveler’s response in driving behavior to the emergency evacuation condition in Section 2, and then presents the traffic evacuation plan for the city of Almere in Section 3. Thereafter, this paper proposes an evacuation framework in S-Paramics to assess the impacts of driving behavior on the evacuation clearance time in Section 4. Section 5 presents the main results and analysis and Section 6 draws the main conclusions and discusses the further research.

2. Traveler’s Response

Driving behavior models are fundamental to the understanding of traffic flow phenomena and form the basis for microscopic traffic simulation models. The determinants which may cause changes in driving behavior can be divided into static and dynamic variables [4]. Static variables remain relatively constant over a longer time period, whereas dynamic variables may change within a moderate period of time. Although the static variables age, driving experience and mood do have an influence on driving behavior, there is very limited research which describes this influence under emergency situations. Dynamic variables that may alter during emergency situations are mental workload and emotions. An increase in mental workload, possibly resulting in perceptual narrowing, may have a significant impact in influencing driving behavior. Emotions also, might play a role during emergency situations. Some authors state that drivers may panic in emergency conditions, causing their driving behavior to change drastically [3]. However, systematic studies of emergency situations have shown that panic seems to be a quite uncommon reaction to these circumstances these circumstances [4-7]. Other emotions like anxiety or hastiness do play a role. For example, Wei [4], Hamdar [9], and Hamdar et.al.[10] report that during evacuations, drivers express anxious behavior due to the mentally demanding conditions, which leads to:

- An increase in velocity resulting in higher acceleration and deceleration rates;
- A high variance in speed due to drivers freezing or slowing down or not being able to cope with a specific threat
- A decrease in headways to pressure other drivers to accelerate or move out of the way;
- An increase in emergency braking and rubber-necking;
- Tendency to disrespect traffic regulations and signals;
- An increase in intensity with regards to speed and braking rates over time.

Knoop [11] has done some empirical analysis on driver behavior when passing by an incident/accident location. It is reported that:

- Average speed drops;
- Queue discharge rate drops.

Hoogendoorn et al. [12] has done quite extensive experiments with a driving simulator, where test drivers were (unexpectedly) exposed to accident scenes, leading to distraction and anxiety. These experiments show that:

- mean velocity and acceleration decrease;
Some of these changes in driving behavior seem to be related to each other. The decrease in headways combined with the increase in speed and the higher speed variance, will presumably result in the increase of emergency braking and the intensity of speed and braking rates. These changes in driving behavior may have an influence on road capacity. For instance, if drivers decrease their headways the throughput on roads could increase. On the other hand, lower headways could make it more difficult to find a gap during lane changing manoeuvres, which on its turn might have a negative impact on capacity. The resulting changes in capacity do affect the evacuation clearance time.

A large amount of researches have proposed methods for computing evacuation time evacuation time (e.g. [13-15], see overview also [16, 17]). Most of them are focusing on developing new traffic flow models, but are not taking into account changes in driving behavior. So the assumption made, is either that driver behavior is not different compared to an average day situation or that the influence can be neglected. The sensitivity analysis on the macroscopic output, however, shows that the input parameters having an influence on flow, density, and average speed are the headways, the speed distribution, and the reaction time [18, 19] etc.

3. Traffic Evacuation Plan of Almere in Case of an Evacuation

The city of Almere is one of Netherland’s fastest growing cities and has more than 180,000 inhabitants. The evacuation scenario in the city of Almere implies a threat of dikes’ breakthrough near the city of Lelystad. The evacuation is planned to start a week before the predicted breakthrough. In the first day, farmers and their cattle will be evacuated. Inhabitants may evacuate voluntarily, but 48 hours before the predicted breakthrough the compulsory evacuation starts. Situated in a polder, the city of Almere has two main exits, one heading to the city of Amsterdam (motorway A6) and the other to the province of Utrecht (motorway A27). Error! Reference source not found. provides an overview of the location of the city of Almere, where the eastern part of the city evacuates via the A27 motorway and the western part uses the A6.

Fig. 1 Overview of the main evacuation routes from Almere

The evacuation of both parts of the city starts simultaneously. The philosophy of the evacuation plan is that the areas near to the motorways are being evacuated first, followed by the adjacent areas. If one zone evacuates, the next evacuation zone is being blocked by a moveable road barrier. After all cars have left the previous zone, the road barrier is removed and the next following zone starts to evacuate. Every area leaves the city using a predefined fixed route. Cars start their trip at collector streets, using only one lane, even if two or more lanes are available. The main reason for doing so is to avoid merging behavior. Since both motorways have two lanes available and also have several onramps, it is possible to evacuate two areas per motorway simultaneously. This adds up to 4 areas evacuating at the same time. The evacuation clearance time has been estimated without the use of a traffic model as the following approach. Per postal code zone the number of inhabitants is known. It is assumed that every car will have 2.4 passengers aboard. Assuming a collector street with a capacity of 1200 veh./hour, evacuation time is estimated by dividing the number of cars over the capacity. Given the planned order of evacuation of the different areas, clearance time is estimated to be less than 18 hours. With the extra travel time to the ‘save area’, total clearance time for the whole city is estimated to be 19 hours. An important property of this evacuation plan is that
traffic has no conflicts at junctions and no weaving areas. The analysis of this study therefore presents a case with a relatively simple traffic situation.

4. Evacuation Framework in S-Paramics

S-Paramics is the widely applicable microsimulation traffic flow modelling system, software for the analysis and design of urban and highway networks. S-Paramics simulates the individual components of traffic flow and congestion, represents the actions and inter-actions of individual vehicles as they travel through a road network [20]. The city of Almere has setup a microscopic simulation model by using S-Paramics. This model with normal peak-hour traffic demand has originally been developed to simulate a normal workday traffic situation and has been calibrated by using the traffic survey data. In order to adjust the model for the simulation of the evacuation plan, the network of S-Paramics model has been adjusted. As the evacuation plan assumes the use of one lane only, even if two or more lanes are available, the model network has been modified to use only one lane. Furthermore, the evacuation traffic demand has been estimated. The main purpose of this study is to investigate the results of the simulation of the evacuation plan and see if it provides new insights:

- What is the total clearance time of the network in case of an evacuation based on the assumptions of the traffic evacuation plan;
- What is the evacuation clearance time if the driving behavior of evacuees during evacuation conditions is different from normal conditions.

The default behavior of drivers in the microsimulation model is based on a ‘normal’ situation. As has been discussed in the previous sections, it is likely that an evacuation will have impact on various features of driving behaviour. This simulation experiment investigates the impact of changes in driving behavior on evacuation clearance time.

4.1. Network setup

The simulation model of Almere covers an area of 15 x 15 km and includes the major roads within and around the city. The number of zones in the model is 276. All junctions, roundabouts, give way and traffic lights are set up based on the real settings. The model is calibrated by comparing the model results with survey data (counts, queues, travel times). The S-Paramics network is adjusted for the evacuation plan, since the traffic is regulated differently and priorities at junctions are changed accordingly. Fig. 2 shows the S-Paramics network.

![Fig. 2. The network of the Almere S-Paramics simulation model](image)

4.2. Traffic demand prediction

The demands matrix in an evacuation condition is different from the normal daily traffic demand. In this case the number of car trips is directly obtained from the transportation plan of the city. The city is divided into postal code
areas, which are implemented in the simulation model. For each zone or postal code area the destination has been pre-defined, heading either to the A6 freeway or to the A27 freeway.

4.3. Behavioral settings and scenarios

In the S-Paramics simulation, the dynamic parameter settings in terms of driving behavior, such as the effect of varying driving characteristics on traffic flows, are being analyzed. In the base model the default settings from S-Paramics are being used (Table 1). Note that in Table 1, the mean time headway is measured in seconds from the front of the vehicle following, to the rear of the vehicle in front, exclusive the time that the following vehicle travels.

Table 1 Settings in the S-Paramics base model

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed Limits</td>
<td></td>
</tr>
<tr>
<td>Motorways</td>
<td>120 km/h</td>
</tr>
<tr>
<td>Provincial roads</td>
<td>100 km/h or 80 km/h</td>
</tr>
<tr>
<td>Urban roads</td>
<td>50 km/h</td>
</tr>
<tr>
<td>Acceleration</td>
<td></td>
</tr>
<tr>
<td>Passenger car</td>
<td>2.5 m/s</td>
</tr>
<tr>
<td>Light vehicle</td>
<td>1.8 m/s</td>
</tr>
<tr>
<td>Heavy vehicle type I</td>
<td>1.1 m/s</td>
</tr>
<tr>
<td>Heavy vehicle type II</td>
<td>1.41 m/s</td>
</tr>
<tr>
<td>Mean headway</td>
<td>1 second</td>
</tr>
<tr>
<td>Minimum gap</td>
<td>2 meters</td>
</tr>
</tbody>
</table>

Amount of researchers reported that variations in time headway, speed, and capacity has been found during the unexpected events [10-12]. For the sake of simplicity, this paper is not going to tackle the variations of the changes in driving behavior due to unexpected events. Aforementioned in section 2, it is found that in earlier studies that headways tend to decreases during evacuation. In this paper we only focus on the mean value changes in speed, acceleration, mean headway and minimum gap distance. The following features in driving behavior of model settings and parameters are taken into account:

A. Speed limits on all roads increase by 10%.
B. The acceleration of all cars increases by 10%.
C. The mean headway of vehicles decreases by 20%.
D. The mean headway of vehicles decreases by 30%.
E. The minimum gap between vehicles if they are driving slowly or stand still reduces by 20%.
F. The minimum gap between vehicles if they are driving slowly or stand still reduces by 30%.

Note that this paper focuses on the qualitative analysis. Therefore the above settings are (arbitrarily) chosen to investigate the impacts of the changes in driving behavior on evacuation clearance time.

An overview of the scenarios is as follows:

- Base model
- Scenario 1: A (speed limit +10%)
- Scenario 2: B (acceleration +10%)
- Scenario 3: A + B
- Scenario 4: C (mean time headway -20%)
- Scenario 5: E (minimum gap –20%)
- Scenario 6: C + E
- Scenario 7: A + B + C + E
- Scenario 8: D (mean time headway -30%)
- Scenario 9: F (minimum gap –30%)
- Scenario 10: D + F
5. Results and Analysis

In the traffic evacuation plan, the evacuation clearance time is calculated by the number of vehicles over the capacity. In the simulation model the evacuation clearance time includes the time the vehicle travel through the network. Fig. 3 illustrates the evacuation clearance time for different scenarios. In the Base model, the clearance time appears to be more than 21 hours, and is higher than the one estimated in the traffic evacuation plan (about 19 hours).

As also can be seen in Fig. 3, the acceleration rate and maximum speed (Scenario 1, 2, 3) do not have any impact on the clearance time. This is probably due to the fact that traffic in evacuation conditions is not in free-flow conditions. So despite the fact that the evacuees show a more aggressive driving behavior (higher acceleration rates and higher speeds), they don’t have sufficient space and time to do so. Therefore, the evacuation clearance times in the first three scenarios do not change compared to the clearance time in the base model.

The minimum distance gap is the gap in meters between vehicles when queued (measured from the front of the vehicle behind to the rear of the vehicle in front). The decrease of the minimum gap and mean time headway may increase the capacity of roads. The lower mean time headway may increase capacity because vehicles are driving closer to each other, which increases the throughput of roads. The reduction of the minimum gap may decrease the queue lengths and thus the probability of spill back. Scenario 4–10 in Fig. 3 show that the decrease of the minimum gap and the decrease of the mean headway significantly reduce the evacuation clearance time. The 20% reduction of the mean headway decreases the clearance time by 8.7% and the 30% reduction of the mean headway decreases the clearance time by 12.6%. Meanwhile, the 20% reduction of the minimum gap decreases the clearance time by 4% and the 30% reduction of the minimum gap decreases the clearance time by 5.5%. The 20% reduction of the minimum gap combined with the 20% reduction of the mean headway decreases the clearance time by 11.8%, whilst the 30% reduction of the minimum gap combined with the 30% reduction of the mean headway decreases the clearance time even more by 17.3%.

Fig. 3 Evacuation clearance time for different scenarios (clearance time in minutes)

Fig. 4 (the left figure is the complete one while the right figure is the zoom-in of the part of the left one) demonstrates the total network outflow during the simulation for different scenarios. The figure shows the number of endangered residents that arrived at their safe destination at a certain moment in time, which differs per scenario. The right figure (Fig. 4) shows that the reduction of minimum gap and mean headway have much more influence on evacuation time than the increase in acceleration rates and in maximum speed.
In this study, the city of Almere has two separate routes to evacuate the residents (see Section 3), the east part heading to the city of Utrecht and the west part to the city of Amsterdam. Fig. 5 provides network outflow patterns for these two routes that are similar to the patterns shown in Fig. 4. This provides additional evidence that the changes in driving behavior have the previously described impacts on evacuation time.

6. Conclusions and Further Research

Driving behavior under evacuation conditions is an important feature for an evacuation model. This paper presents a microscopic S-Paramics evacuation model to assess the impact of changes in driving behavior on the evacuation clearance time. Based on the evaluations of 10 scenarios, the results provide some interesting findings:

- The increase in acceleration rate may not have an impact on the evacuation clearance time;
- The increase in maximum speed may not have impacts on the evacuation time;
- The reduction of the mean headway significantly reduces the evacuation time;
- The reduction of the minimum gap distances significantly decreases the evacuation time.

These findings provide evidence that driving behavior plays an important role in an evacuation model, because it shows to have a significant impact on the evacuation clearance time. Since there is no research that provides any quantitative insight in these changes in driving behavior, this paper makes some simple assumptions in terms of driving behavior, such as a 20% or 30% reduction of minimum gap distances. These assumptions are rather arbitrary and should be verified by empirical data. Also, the conclusions are only valid for the applied intervals in parameter values.
Furthermore, the more aggressive driving behavior may also lead to less safe driving in the evacuation conditions. This should be evaluated as well. Finally, the specific evacuation strategy of the city of Almere is characterized by relatively smooth traffic flows. One of the key elements of the traffic evacuation plan is that bottlenecks are avoided by supplying only one lane per evacuation route. This leads to a low amount of lane merging movements. In other cases with dense traffic and more lane changing conflicts between cars, a lower headway could also turn out to have a negative impact on capacity as merging and weaving becomes more difficult due to smaller gaps.

References