THE IMPACTS OF DRIVING BEHAVIORS ON TRAFFIC SAFETY IN CASE OF EVACUATION

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ABSTRACT

The driving behaviour of travellers has been found to be different in case of emergency conditions compared to normal traffic conditions. In this paper, we show how this different driving behaviour has an impact on traffic safety. 8 scenarios with different parameter settings such like speed limit, acceleration rate, mean time headway and minimum gap distance has been conducted in an S-Paramics microscopic simulation model framework to investigate this impact. The results demonstrate that the reduction both in time headway and in minimum gap distance significantly increase the unsafe traffic flows. It is also found that increasing in speed limits and acceleration rate play a smaller role in traffic safety.

INTRODUCTION

Natural disasters such as hurricanes, floods, big storms, and bushfires have caused massive damages as well as loss of life. The North Sea flood of 1953 and the associated storm combined to create a major natural disaster which affected the coastlines of the Netherlands and England on 1 February 1953. In the Netherlands 1835 people were killed. The Veiligheidsbureau (safety department) in the province of Flevoland has the task to prepare plans to evacuate its inhabitants. Part of this plan is the setup of a traffic circulation plan for every municipality during an evacuation. All of these plans will be integrated into an overall traffic circulation plan for the province of Flevoland. According to the Transportation Plan of the city of Almere (one city in the province of Flevoland) (Gemeente Almere (Almere Municipality) 2008)), the Netherlands should be prepared to undertake the effects of flooding and the related measures that should be taken in case of a threat of flooding.

The traffic circulation plan of the city of Almere has defined how the people should and will be evacuated in case of an emergency situation. This traffic circulation plan assumed that the driving behaviours for evacuees are ‘normal’ – under the normal traffic conditions. Traffic flows under evacuation conditions are the result of the behaviours of the endangered residents. That is how they response each other (e.g. minimum gap, headways etc.) under evacuation conditions. Therefore, the endangered residents may have different behaviours compared with the behaviours under the normal traffic conditions. However, the driving behaviour, the important features for an evacuation model (Tu et al. 2009), has not been taken into account In the traffic circulation plan. This motivates the need to study the driving behaviours in case of evacuation conditions.

Amount of researches have been undertaken to setup an evacuation model. The available evacuation models combining microscopic or macroscopic simulation model aimed to compute the duration of a complete evacuation, to quantify the effects of traveller information and evacuation management strategies, and to predict the spatial implications of the evacuation. These models concentrate on the traffic characteristics throughout the evacuation, such as speeds and traffic volumes, and can identify where bottlenecks are likely to occur. The driving behaviour may have significant impacts on traffic safety. The major drawbacks of these models are the lack of safety analysis due to the traveller response behaviours under evacuation condition (Robinson et al. 2009).

To fill these gaps, this paper proposes a Paramics Microscopic simulation based framework to evaluate the effects of driving behaviours on traffic safety under evacuation condition. The remainder of this paper outlines the traveller response in driving behaviours to the emergency evacuation condition in Section 2, and then presents the traffic circulation 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 behaviours on traffic safety in Section 4. Section 5 presents the main results and analysis and Section 6 draws the main conclusions and discusses the further research.

TRAVELLER RESPONSE AND TRAFFIC SAFETY

The drivers' psycho-behaviour response in emergency conditions can be divided into situation awareness and decision making (Wei et al. 2008). Situation Awareness (SA) involves being aware of what is happening around the drivers to understand how information, events, and their own actions will impact their driving behaviours, both now and in the near future. Decision making then relates to identifying and assessing the various alternatives open to the individual and leading to the selection of one action for execution. This selection will impact their driving behaviours as well. In an evacuation condition, for example, one driver may make a decision to keep short gap distance. In this context, traveller response behaviours under evacuation condition are the important features for an evacuation model (Tu et al. 2009). Some of these behaviour features are specific to an emergency evacuation (e.g. high levels of anxiety, or panic, and uncertainty, c.g. unfamiliarity), which play an important role in the capacity of a road network and hence the network performance under evacuation conditions.

When focussing on driver behaviour it is useful to understand which determinants are responsible for the behavioural changes under emergency conditions. A state of the art review (Hoogendoorn 2010) distinguishes static and dynamic variables. The static variables of drivers are age, driving experience and mood. Although all of these variables appear to have an influence on driving behaviour in general, specific research in case of exceptional events is lacking. The first dynamic variable is “mental workload and perceptual narrowing”. Possibly, an evacuation leads to an increase in mental workload, leading to deterioration in the performance of the driving task. Although there is some evidences of this phenomenon during incidents, this has not been investigated yet for evacuations. The second dynamic variable is called “emotions”. As is often mentioned, drivers may panic in emergency conditions, causing their driving behaviour to change drastically (Ni 2006). Contrary to this, however, a majority of studies notice an absence of panic in case of evacuations and disasters (Hoogendoorn 2010). An analysis of the behaviour of evacuees from the World Trade Center revealed that only 0.8% of them showed panic or irrational behaviour. Hoogendoorn (2010) concludes that emotions in general do not play a substantial role in driver behaviour.

The sensitivity analysis on the macroscopic output shows that the input parameters having an influence on the flow, density, and average speed are the headways, the speed distribution, and the reaction time (Daganzo 1999; Pel 2007; Pel et al. 2010). Therefore, it is expected that drivers’ behaviour may change regarding gap acceptance, minimum time headways, acceleration rate, velocity and car following (Hamdar 2004). Driving behaviour models are fundamental to the understanding of traffic flow phenomena and form the basis for microscopic traffic simulation models. Consequently, driving behaviour may have significant impacts on the traffic safety.

One of the world’s largest public health and injury prevention problems is traffic crashes. The problem is all the more acute because the victims are overwhelmingly healthy prior to their crashes. A common measure used in assessing traffic safety is to set up methods for observing conflicts between vehicles. When operating a vehicle the driver is continually faced with the problem of avoiding collisions with other vehicles, pedestrians, and various obstacles that may lie in the path of travel. To prevent potential collisions, the driver may initiate steering or braking actions or some combination of both (Sidaway et al. 1996). Appropriate regulation of the timing and control of such actions requires the driver to anticipate the time of the impending collision. This time remaining before the collision, often termed Time To Collision (TTC), is critical information for the driver in enabling prospective control of braking or steering behaviour. As vehicles are nearer to each other, and at increased speed, the risk of a crash will increase. In case of an evacuation, the way drivers’ steer or break actions (driving behaviours) vary with normal traffic conditions. Thus, it is expected that the driving behaviour may have significant impacts on TTC.

TRAFFIC CIRCULATION PLAN OF ALMERE IN CASE OF AN EVACUATION

The city of Almere is one of Netherlands’ fastest growing cities and has more than 180,000 inhabitants. The evacuation scenario implies a threat of dikes´ breakthrough near the city of Lelystad. The evacuation starts a week before the predicted breakthrough. In the first day, farmers and their cattle are being evacuated. Inhabitants may evacuate voluntarily. 48 hours before the predicted breakthrough the compulsory evacuation starts. Situated in a polder, there are two main destinations, one heading to the city of Amsterdam (motorway A6) and the other to the city of Utrecht (motorway A27). **Figure 1** provides an overview of the city of Almere, where the eastern part of the city evacuates via the A27 motorway (to the city of Utrecht) and the western part uses the A6 (to the city of Amsterdam).

The evacuation of both parts of the city starts simultaneously. The philosophy of the evacuation is that the areas near to the motorways are being evacuated firstly, followed by the adjacent areas. If one area evacuates, the evacuation route from the next zone is being blocked by a moveable road barrier. Cars already can take position and queue up. After all cars have left the first zone, the road barrier is removed and the next area starts to evacuate. Every area leaves the city using a predefined fixed route. Cars start their way at collector streets, using only one lane to avoid the conflicts, even if more than one lane is available. When approaching the motorway, the onramp offers a one lane connection.

The optimal plan has been developed in an iterative session without the use of a traffic model (Gemeente Almere (Almere Municipality) 2008)). The following approach has been conducted. Per postal code zone the number of inhabitants is known. It is assumed that every car has 2.4 passengers onboard. Assuming a capacity of a collector street of 1200 veh/hour, evacuation time is estimated by dividing the number of cars by that capacity. Given the planned order of evacuation of the different areas, clearance time is estimated to be less than 18 hours. Given the extra travel time to the 'save area', total clearance time for the whole city is estimated to be 19 hours, not taking into account the time that is necessary for moving road blockages.

An important property of this evacuation is that traffic has no conflicts at junctions and no weaving areas. The analysis of this traffic circulation plan therefore demonstrates a case with a relatively simple traffic situation.

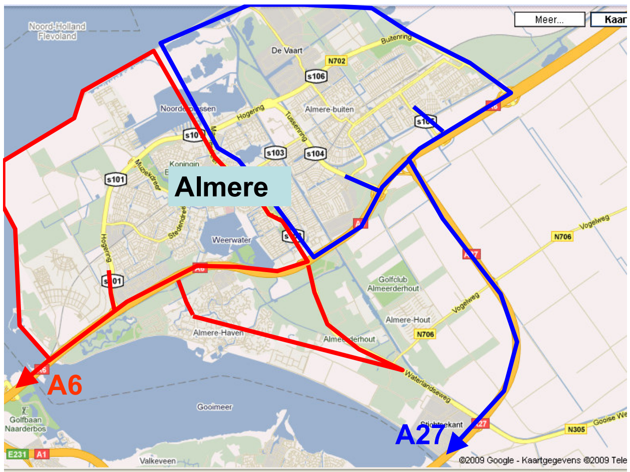


Figure 1 *Overview of the main evacuation routes from Almere*

EVACUATION FRAMEWORK IN S-PARAMICS

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 (Druitt 1998). The city of Almere has setup a microscopic simulation model by using S-

Paramics. This model has originally been developed to simulate a normal workday traffic situation and has been calibrated by using the traffic survey data. It appeared to be relatively simple to adjust the model in order to simulate the traffic circulation plan in case of an evacuation. The objectives of this study are to investigate the results of the simulation of an evacuation and to see if it provides new insights:

- What is the traffic safety of the network in case of an evacuation based on the assumptions of the traffic circulation plan;
- What is the traffic safety if the driving behaviour of evacuees in evacuation conditions is different from normal conditions?

The behaviour of drivers in the microsimulation model is based on a 'normal' situation. It is likely, however, that the behaviour during evacuation will have higher variations. This study assesses the impacts that variations in driving behaviour might have on traffic safety.

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 is 276. All junctions, roundabouts, give way and traffic lights are modelled and function like they do in real world. The model is calibrated by comparing the model results with survey data (counts, queues, routes). The Paramics network is adjusted for the evacuation plan, since the traffic is regulated differently and priorities at junctions are changed accordingly. **Figure 2** shows the layout of the network of the Almere S-Paramics simulation model.

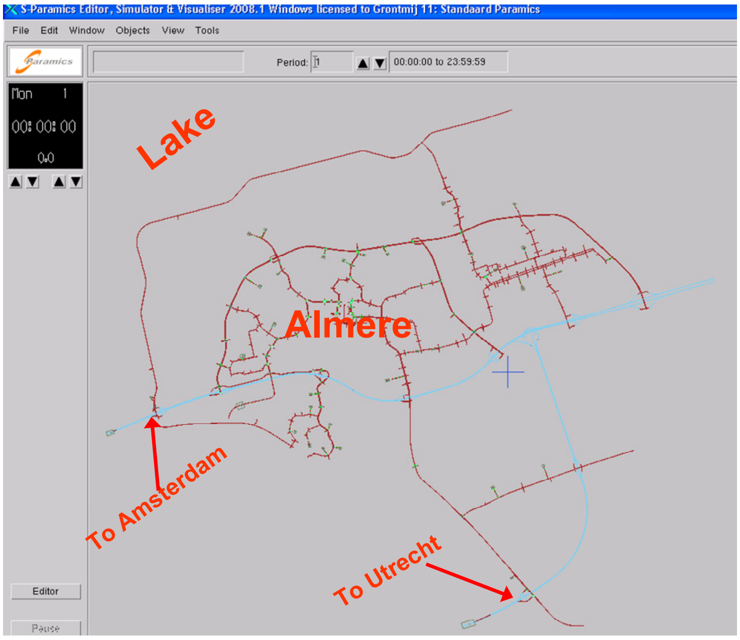


***Figure 2** The network of the Almere S-Paramics simulation model*

Traffic demand estimation

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 taken over from the transportation plan of the city, as has been described in Section 3. The city is divided into postal code areas, which are implemented in the simulation model. For every area the destination has been specified, being either the A6 motorway or the A27 motorway.

Evacuation strategy

The evacuation strategy, where first the inhabitants near the motorway are permitted to leave, is also implemented in the model. Others have to wait until the first areas are cleared. In the model this strategy is implemented by means of stop lights, representing the road blockages. Say we have three zones (A, B and C) that evacuate after each other: if zone A starts, the outgoing roads of zones B and C are being blocked. During the evacuation of zone A, the drivers from other zones already can drive towards the road blockage. Only if all inhabitants have left zone A, the blockage of zone B is removed. In the model the stop light turns to green. Inhabitants from zone C have to wait until the evacuation of zone B is completed.

Traffic safety indicator

There are different safety indicators for different levels of approach. In case of driving behaviours the best approach is to consider interactions between individual vehicles, rather than between vehicle flows. These indicators include, for example, time-to-collision, speed difference between (two successive) vehicles, gap distance between vehicles etc.
The Time-To-Collision (TTC) notion has been applied beneficially as a safety indicator in safety analysis (Minderhoud and Bovy 2001; Dijkstra et al. 2007). A TTC value at an instant *t is* defined as *the time that remains until a collision between two vehicles would have occurred if the collision course and speed difference are maintained).* The time-to-collision of a vehicle-driver combination *i* at time instant *t* with respect to a leading vehicle *i-1* can be calculated with:

$$TTC_i = \frac{X_{i-1}(t) - X_i(t) - l_i}{V_i(t) - V_{i-1}(t)} \quad \forall V_i(t) > V_{i-1}(t) \tag{1}$$

where

V denotes the speed
X the position, and
l the vehicle length

It is assessed whether the interaction between vehicles is a conflict and how serious this conflict is. In general, the lower TTC-value, the higher possibility is a conflict. A critical or threshold value for safety indicator should be chosen to distinguish relatively safe and critical encounters. On the basis of a driving simulator experiment, Hogema and Jassen (1996) concluded that a minimum TTC value of 3.5 second for the non-supported drivers, 2.6 second for supported drivers. For the safety concern, they chose 2.6 second as the threshold value. Hirst and Graham (1997) reported that a TTC measure of 4 second results in too many false alarms and they proposed 3 seconds which produced the lease number of alarms. Minderhoud and Bovy (2001) concluded that different values are use for critical TTC in different studies. In contrast to the classical TTC-indicator, they proposed Time Exposed Time-to-collision (TET) which could take the full course of vehicles over space and time into account. Lu et al. (2001) studied different accident risk classes based on three critical TTC values at junctions. TTC with a value lower than 1 second is considered as high risk, with a value between 1 and 1.5 second as moderate risk and with a value between 1.5 and 2 second as low risk. Van der Horst (1990) concluded that TTC value should be less than 2.5 seconds and Archer (2005) reported even lower critical TTC value, less than 1.5 second. Although the threshold value is still an open question, we test three different TTC threshold values in this paper (*TABLE 1*).

TABLE 1 *Risk levels and TTC values*

Risk level	TTC values
Low	1.5~2.0 seconds
Moderate	1.0~1.5 seconds
High	<1.0 seconds
Total	<2.0 seconds

Behavioural settings

In the S-Paramics simulation, the dynamic parameter settings in terms of driving behaviors like the effect of varying driving characteristics on traffic flows is being analyzed. In the base model the basic settings from S-Paramics are being used (*TABLE 2*).

TABLE 2 *Parameters settings*

Parameters		Values
Speed Limits	Motorways	120 km/h
	Provincial roads	100 km/h or 80 km/h
	Urban roads	50 km/h
Acceleration	Passenger car	2.5 mpss
	Light vehicle	1.8 mpss
	Heavy vehicle type I	1.1 mpss
	Heavy vehicle type II	1.41 mpss
Mean headway		1 second
Minimum gap		2 meters

To the best of our knowledge, little has been undertaken on the quantification researches of the driving behaviour under evacuation conditions. Some studies have been done on the qualification. Hamdar (2004)and Hamdar and Mahmassani (2008), for example, reported that during evacuations there would be some kind of high anxiety (mental workload and perceptual narrowing) behaviour that leads to:

- an increase in velocity resulting in higher acceleration and deceleration rates;

- high variance in velocity due to drivers freezing or slowing down for not being able to cope with a specific threat;
- sudden lane change;
- a decrease in headways to pressure other drivers to accelerate or move out of the way;
- emergency braking and rubber-necking;
- an increase in intensity with regard to velocity and braking rates over time;
- tendency to disrespect traffic signals and signals;

Based on pedestrian experiments, some researchers (e.g. (Helbing and Vicsek 1999)) show changes in behaviour (moving closer together and try to move faster) and support above assumptions and conclude that there would be an impact of evacuations on driving behaviour (a review refer to (Hoogendoorn 2010)). Yet, more research is recommended in order to be able to describe the underlying processes that lead to changes in driving behaviour.

In order to qualifically assess the impacts of driving behaviours in evacuation conditions, the main assumption in this paper is that during an evacuation, people are hastier due to the pressure of leaving the area in time. Therefore, increase in velocity, acceleration, and deceleration rates and decrease in (time/distance) headways will be assessed. The following variations of model attributes 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 time headway of vehicles decreases by 20%.
D. The mean time 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%.

Scenarios

Based on above variations of model attributes and parameters, the following scenarios have been set up and simulated:

- ❖ Base model (normal settings, see *TABLE 2*)
- ❖ Scenario 1: A (speed limit 10%↑)
- ❖ Scenario 2: B (acceleration 10%↑)
- ❖ Scenario 3: C (mean time headway: 20%↓)
- ❖ Scenario 4: E (minimum gap: 20%↓)
- ❖ Scenario 5: C + E
- ❖ Scenario 6: D (mean time headway: 30%↓)
- ❖ Scenario 7: F (minimum gap: 30%↓)
- ❖ Scenario 8: D + F

RESULTS AND ANALYSIS

All the evacuated vehicles from the city of Almere leave either for Amsterdam (via A6 motorway) or for Utrecht (via A27 motorway) (see **Figure 2**). In order to make the results of all scenarios comparable, two links (one link to Amsterdam, one link to Utrecht) are selected in the road network. Total outflows, which are more or less the same numbers for all scenarios, are the sum up of these flows on those two links.

As can be seen in **Figure 3**, **Figure 4**, **Figure 5**, and **Figure 6**, scenario 1 (speed limit increase by 10%) reduces conflicts by 3% at low risk level, increases conflicts by 8% at moderate risk level, and reduces conflicts by 7% at high risk level. In total (TTC values less than 2 seconds) scenario 1 reduces conflicts by 2%.

Scenario 2 (acceleration rate increase by 10%) increases conflicts by 7% at low risk level, by 20% at moderate risk level, and by 6% at high risk level. In total scenario 2 increases conflicts by 10%. Scenario 2 demonstrates clear conclusions that higher acceleration rate leads to more conflicts and hence less safe are the flows.

The minimum time headway is measured in seconds form the front of the vehicle following, to the rear of the vehicle in front. Scenario 3 reduces time headways by 20% which results in increasing conflicts by 399% at low risk level, by 346% at moderate risk level, and by 412% at high risk level. In total scenario 3 increases conflicts by 392%. Scenario 6 reduces time headways further, by 30%, which results in increasing conflicts by 699% at low risk level, by 635% at moderate risk level, and by 723% at high risk level. In total scenario 6 increases conflicts by 694%. It appears that higher reduction in time headway leads to less safe (more conflicts) traffic flows.

The minimum distance gap is the gap in meters between vehicles when queued (measured from the front of vehicle behind, to the rear of the vehicle in front). Scenario 4 reduces the minimum gap by 20% which leads to the increasing conflicts by 71% at low risk level, by 77% at moderate risk level, and by 45% at high risk level. In total scenario 4 increases conflicts by 59%. Scenario 7 reduces the minimum gap by 30% which leads to the increasing conflicts by 53% at low risk level, by 50% at moderate risk level, and by 29% at high risk level. In total scenario 7 increases conflicts by 40%. It appears that reduction in the minimum gap leads to more conflicts in general.

Scenario 5 and scenario 8 reduce both in the minimum time headway and in the minimum gap. Scenario 5 reduces the time headway by 20% and the minimum gap by 20% which results in increasing conflicts by 515% at low risk level, by 472% at moderate risk level, and by 520% at high risk level. In total scenario 5 increases conflicts by 507%. Scenario 8 reduces the time headway by 30% and the minimum gap by 30% which results in increasing conflicts by 877% at low risk level, by 814% at moderate risk level, and by 892% at high risk level. In total scenario 8 increases conflicts by 868%.

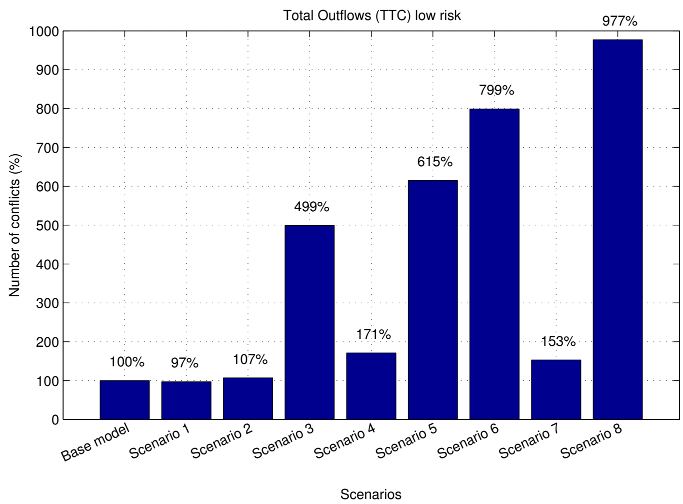


Figure 3 *Number of conflicts (%) for different scenarios at low risk level (base model as 100%; the other scenarios relative to the base model)*

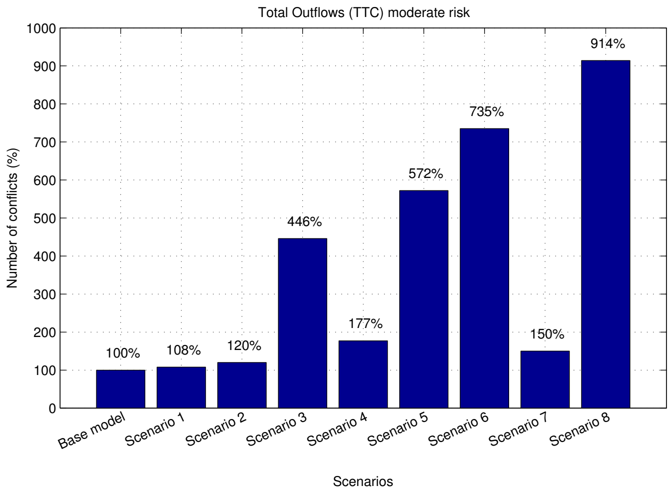


Figure 4 *Number of conflicts (%) for different scenarios at moderate risk level (base model as 100%; the other scenarios relative to the base model)*

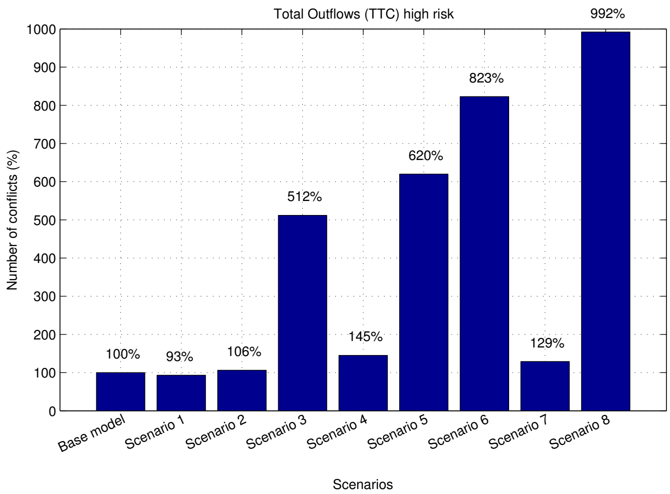


Figure 5 *Number of conflicts (%) for different scenarios at high risk level (base model as 100%; the other scenarios relative to the base model)*

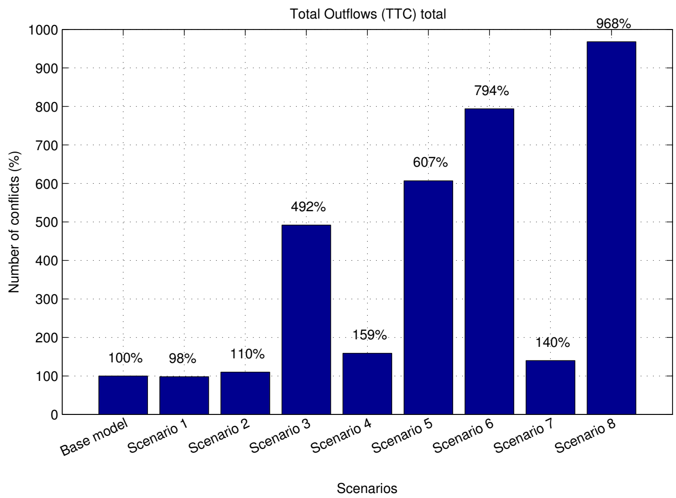
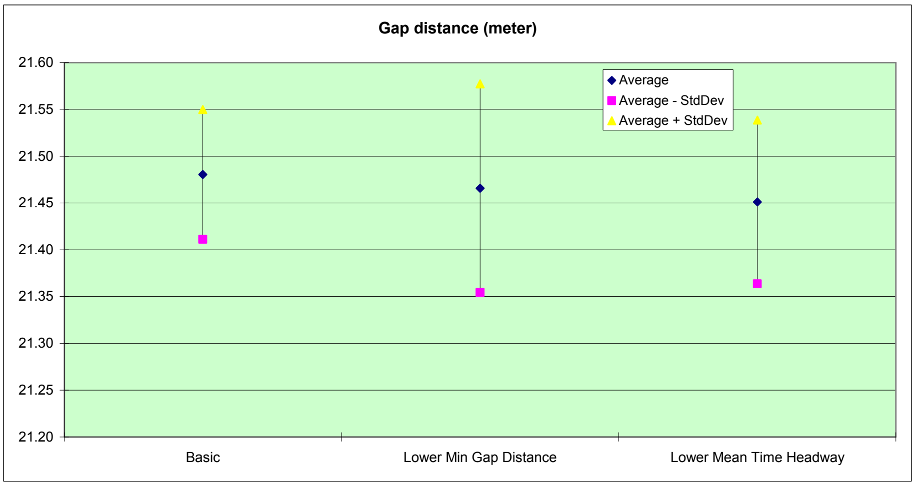
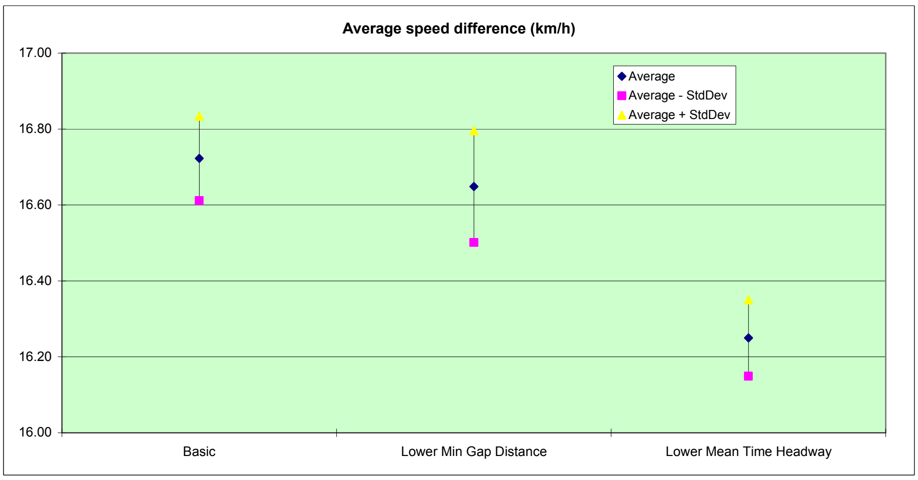


***Figure 6** Number of conflicts (%) for different scenarios at total level (base model as 100%; the other scenarios relative to the base model)*



(a) Gap distance (meter)



(b) Average speed difference (km/h)

***Figure 7** Gap distance (a) and average speed difference (b) under different scenarios*

Figure 7 shows the gap distance and average speed difference under three cases (basic, lower min gap distance (20% lower), and lower mean time headway (20% lower)). As can be seen in **Figure 7** (a), the average absolute gap in meters does drop slightly when both min gap and headway is reduced. In **Figure 7** (b), it is found that the average speed difference also drop slightly when both min gap and headway is reduced. From the above equation (eq. (1)), it can be seen that this decrease in relative speeds in conjunction with only a very minor drop in distance results in overall decreases in the number of small gaps (in seconds).

Above figures illustrate that lower time headway combined with lower minimum distance gaps (scenario 3~8) have much more impacts on traffic safety than an increase in speed and acceleration rates (scenario 1 and scenario2). Thus, scenario 3-8 should be closer checked. This Paramics Almere network only has two general exits (To Amsterdam and To Utrecht (see **Figure 2**)). *TABLE 3* shows the number of conflicts per scenarios for two directions. It provides the similar trends for these two directions as shown in above figures (**Figure 3**, **Figure 4**, **Figure 5**, and **Figure 6**). Reductions in time headway and in the minimum gap lead to more conflicts and hence less safe traffic flows. *TABLE 3* also demonstrates the different relative conflicts to base model between two directions. Vehicles generally try not to hit each other and adjust their speeds in order to achieve this. This may due to the different speed limits on these two freeway exits. The speed limit for Amsterdam exit is 100 km/h and the speed limit for Utrecht exit with 2 lanes is 120 km/h. 35350 vehicles leave for Amsterdam (with 3 lanes) and 41050 vehicles leave for Utrecht (with 2 lanes). That means the traffic flows to Utrecht are less free than the one to Amsterdam. This may also lead to different conflicts in *TABLE 3*.

***TABLE 3** Number of conflicts (%) for two directions (To Amsterdam and To Utrecht)*

To Amsterdam							
Risk level	Base model	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
High risk	100%	432%	137%	474%	702%	110%	837%
Moderate Risk	100%	418%	180%	509%	697%	131%	848%
Low risk	100%	499%	163%	524%	792%	135%	995%
Total	100%	443%	153%	493%	720%	121%	874%
To Utrecht							
Risk level	Base model	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
High risk	100%	719%	167%	999%	1136%	180%	1392%
Moderate risk	100%	493%	172%	675%	797%	182%	1022%
Low risk	100%	500%	185%	765%	811%	183%	948%
Total	100%	592%	174%	839%	947%	182%	1161%

Furthermore, *TABLE 3* shows that scenario 3~8 increase the conflicts at all three risk levels. Although the threshold TTC value for a conflict is still an open question, it may conclude that more aggressive driving behaviour in case of evacuation may generally lead to less safe traffic flows.

CONCLUSTIONS AND FURTHER RESEARCH

Driving behaviours under evacuation condition are different compared with the behaviours under normal traffic condition. This paper sets up a microscopic S-Paramics evacuation model to assess the impacts of driving behaviour on the traffic safety. The traffic safety indicator is measured as the number of conflicts between individual vehicles and the time-to –collision lower than a threshold value is considered as a conflict. The more conflicts, the less safe traffic flows are. Based on the evaluations of 1 base model and 8 scenarios in terms of different parameters settings like speed limits, acceleration and deceleration rate, and time (or distance) headways, the preliminary results provide some findings:

- Speed limits increasing by 10% have very slight impacts on traffic safety, only resulting in the conflicts reduction by 2% on average;
- Acceleration rate increasing by 10% have slight impacts on traffic safety, only resulting in the conflicts increasing by 10% on average;
- Reduction in time headway dramatically increases the number of conflicts and leads to less safe traffic flows. Time headway reduction by 20% increases the conflicts by about 407% and reduction by 30% increases the conflicts by 694%.
- Reduction in minimum gap distance strongly increases the number of conflicts and results in less safe traffic flows. Minimum gap reduction by 20% increases the conflicts by 60% and reduction by 30% increases the conflicts by 41%.
- Above trends also are confirmed at different risk levels: low risk level (TTC: 1.5~2.0 seconds), moderate risk level (1.0~1.5 seconds), and high risk level (<1.0 second).

To conclude, for changes of the reduction both in time headway and in minimum gap distance, the conflicts increase and the traffic flows are less safe. These results provide the evidences that driving behaviours play an important role in an evacuation model, especially on the traffic safety. For example, more aggressive (lower minimum gap distance and lower time headway) and/or hastier driving behaviours in case of evacuation conditions lead to less safe traffic flows. Policymakers and traffic managers should evaluate the driving behaviour during evacuation conditions when the traffic safety is analyzed.

This paper makes some simple assumptions in terms of driving behaviours, such as 20% or 30% reduction of time headways. These assumptions are rather arbitrary and should be verified, for example, by empirical data. The findings from this paper are only based on two main freeway links. This also should be further tested by more links, even by urban links. Furthermore, this paper only investigates the traffic flows under a strict evacuation planning (without capacity problem). It will be interesting to analyze the traffic flows varied by different traffic flow conditions (low versus high speeds, different road types, congestion versus free-flow etc.).

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