Title: *If things do go wrong: lessons learned concerning traffic management during mass evacuation in case of possible extreme flooding in The Netherlands*

Corresponding author:
Ir. Klaas Friso
Goudappel Coffeng BV
Postbus 161
7400 AD Deventer
The Netherlands
kfriso@goudappel.nl
T: 0570-666812
M: 06-11519996

If things do go wrong: lessons learned concerning traffic management during mass evacuation in case of possible extreme flooding in The Netherlands

Klaas Friso[1], Kasper van Zuilekom[2], Bas Kolen[3], Stephanie Holterman[3]

[1] Goudappel Coffeng BV, P.O. Box 161, 7400 AD Deventer, The Netherlands, kfriso@goudappel.nl
[2] University of Twente, Faculty of Engineering, Center for Transport Studies, P.O. Box 217, 7500 AE Enschede, The Netherlands, k.m.vanzuilekom@utwente.nl
[3] HKV Consultants, P.O. Box 2010, 8203 AC Lelystad, The Netherlands, b.kolen@hkv.nl, s.holterman@hkv.nl

Abstract. By using transport models in case studies for preventive evacuation of coastal and river areas in case of possible extreme flooding many insights have been gained with respect to the modeling of possibilities and restrictions of mass evacuation. Limitation of the road capacity is an important factor in the delay during evacuation. In the case studies several traffic management strategies have been examined. It turns out it is impossible to perform a total preventive evacuation for the coastal area in a realistic 48 hour time span. For river areas it seems possible to complete a preventive evacuation in a realistic time span of 72 hours. The results are based on transport models using the Evacuation Calculator for static and MaDAM for dynamic calculations. It is described which lessons can be learned from these calculations and which extensions can be made to perform improvements with respect to the modeling of such scenarios.

Keywords: traffic management, mass evacuation, transport model, Evacuation Calculator, MaDAM.

1 Introduction

Water plays a key role in the safety of the Netherlands. Up to 65% of the country, also an area where most of the economic activities take place, is threatened by either sea of rivers. This is a situation that requires permanent attention. If parts of the Netherlands are threatened to flood, large amounts of people have to be leaded to safe areas in short time. This will lead to major traffic problems on the trunk roads towards safe areas.

For crisis management in relation to transport management is generally a set of prescriptions in a conceptual model used with four basic steps [1]:

- *Plan*: The planning of interventions to ward off a disturbance or threat.
- *Do*: Implementing the actions in accordance with the plan.
- *Check*: Check whether the actions develop as expected, but also setting deviations from the expected picture of the situation (weather conditions)
- *Act* (or *Improve*): Adapt the actions to changing circumstances.

When deciding to evacuate, there are questions as:

- When leaving?
- What is the destination ?
- How (car, bus, train, cycling or walking)?
- By which route?

To be well prepared to take the right measures it is for crisis managers important to know what the effect will be of a certain measurement. If once a strategy in evacuation has been chosen it is very difficult to make adjustments because it is nearly impossible to change directions of the whole society. Only minor adaptations can be made. A framework should be made existing of different scenarios (more or less evacuation time, small or large size of evacuation zone) and different strategies for evacuation, so the crisis managers can compare these with the real situation and can choose what is best to do.

In 2008 two studies were carried out with respect to the modeling of the traffic of a preventive evacuation of inhabitants from threatened areas to safe areas [2] [3]. The purpose of the studies was to investigate what are the possibilities and restrictions in the preparations in the first step of crisis management: the planning of interventions. The focus was to gain insights in the influence of the road capacity for the needed evacuation times in case of several strategies for mass evacuation and traffic management because of a possible extreme flooding. In the studies the coastal area as well as the river area in the Netherlands has been subject of the research.

In this paper we will discuss the transport models used in both studies, some of the results, which lessons we can learn and what possible next steps might be in the modeling of mass evacuation.

This paper is the second part of a triptych in which we focus on the modeling approach. The first paper [4] of the triptych focuses at the evacuation process and strategies in case of a mass evacuation, the third paper [5] of the triptych focuses at the crisis management.

2 Evacuation modeling on national scale in the Netherlands

In this chapter the modeling tools are described which are used for the evacuation calculations on national scale.

2.1 Evacuation Calculator

The calculations in both studies have been performed with the Evacuation Calculator, a tool that calculates evacuation times using a specified traffic management in a so-called static situation. The second aim of the Evacuation Calculator is to determine the weak links in infrastructure during the evacuating process. It focuses on trip production en distribution, and can take into account both people and cattle. The Evacuation Calculator has also been applied for more than 30 dike ring areas in the Netherlands and Germany. A full description of the working principles of the Evacuation Calculator is given in [6] [7].

OmniTRANS is used as supporting Traffic Model for the Evacuation Calculator as part of the RWS-DWW Flood Management System. The available road network covers the whole of the Netherlands. The area is split into zones using the four digit postal code as spatial scale. OmniTRANS is suited for both static and dynamic traffic assignment models.

Combined with a departure profile, which indicates the departures of people over time, the number of trips per zone per interval can be calculated. The Evacuation Calculator uses a departure profile that is based upon earlier experiences with evacuations during hurricanes in the United Stated of America [8]. This is the logistic curve; also known as the S-curve. In the studies performed it is assumed that 50% of the peoples has started evacuating after 7 hours. Because preventive evacuations hardly occur there exists few data concerning departure profiles. Also circumstances like time of the day, weather conditions and the type of thread can be of influence at the departure profile. Another influence to the departure profile will be the communication and decision making of the evacuation by the government and local authorities.

The Evacuation Calculator distributes the number of trips for all source zones over the different exits available. For this distribution Evacuation Calculator offers four standard options:

- *Reference*: The evacuees from each zone are equally distributed over all possible exit points. This strategy approaches a situation in which no direction is given in the evacuation process. The evacuees choose their own preferred exit. As a result there will be an imbalance in the amount of evacuees at the exit points, relatively many car kilometers will be made and inside the threatened area will be crossing flows at crossroads. This situation brings circumstances that better can be avoided.
- *Nearest exit*: People will leave for the nearest exit point in this strategy, regardless of road capacity and use of this exit. This strategy gives priority to the minimization of car kilometers. There will be no crossing flows so that the chance of queues and accidents will be reduced. However, the capacity of the network will not be used optimally.
- *Traffic management*: In this strategy also the travel distance will be minimized but conditionally to the use of the exits proportional to their capacity. In this way directed, convergent, non-crossing traffic flows to the

exit points are realized. In the assignment it becomes visible that there arise areas that outflow to one or more exit point, so-called outflow areas. This will lead to a reduction of one big complex evacuation problem to a number of isolated less complex sub-problems. However, it is thinkable that the arisen outflow areas do not fit with local circumstances. Knowledge of local circumstances can be reason for modified outflow areas, This is mad possible with the following strategy *outflow areas.*

- *Outflow areas*: The user may select any part of the area which needs to be evacuated which have become visible with strategy *Traffic management* to outflow to one or more exit points, so-called outflow areas. *Traffic management* now distributes the inhabitants of this partial evacuation over the selected exit points. The result of the model will never be better than with the strategy *Traffic management*, but copes better with possibilities and limitations of the local circumstances.

Crossing flows of traffic on the network will lead to avoidable waiting times and bring along a high risk of disturbances such as accidents. The last three distribution options avoid crossing traffic flows whereas the first option will most certainly trigger them.

The following assumptions are made in the Evacuation Calculator:

- *People present*: All inhabitants are assumed to be present at their homes when the preventive evacuation call is there.
- *Average velocity*: The travel velocity depends amongst others on the type of roads, the conditions of the roads and the occurrence of traffic jams. An average velocity of 20 km/h is assumed in the threatened area. Because it is very uncertain of what the progress of traffic in this area will be, it is permitted to use this conservative speed.
- *Correction factor exit capacity*: The capacity of the exits depends on the road type and on expected traffic jams at or near the exit. If traffic jams outside the evacuated area are expected which reduce the capacity of the exit, the capacity of the exit in the model should be reduced by a reduction factor.
- *No disturbances*: It is assumed that during the evacuating process there will be no disturbances that influence the traffic, like car accidents, fallen trees etc.
- *Other traffic*: The organization of evacuation assistance, traffic management and other rescue and help services is not incorporated in the model.
- *Empty network*: The road network is supposed to be empty at the beginning of the evacuation. Because a preventive evacuation is considered this seems a reasonable assumptions. The threats are known and the planning of the evacuation is fully operational and are communicated (e.g. people don t go to work anymore).
- *Evacuation route*: The choice of the evacuation route is made at the beginning of the evacuation and will not be adjusted during the evacuation.

The population is split in self reliant and not self reliant people. It is assumed that 80% of the self reliant [9] will evacuate by car with on average 2.26 persons per car [10] (441 cars per 1000 inhabitants in 2007). 20% of the self reliant people will evacuate by bus with an average capacity of 25 persons [9]. The not self reliant people will be evacuated by different means of vehicles (on average 5 persons per vehicle).

2.2 Macroscopic dynamic assignment

The speed at which traffic can move through the network is determined by the physical characteristics of the road and the interaction with other traffic. Under congested conditions, the interaction with other traffic becomes a limiting factor. These dynamics of evacuation traffic is not covered in the Evacuation Calculator which uses static assignments in which the average conditions are represented. Therefore, for some interesting scenarios, modeling of congestion dynamics using dynamic assignments were performed by the tool MaDAM in OmniTRANS (Macroscopic Dynamic Assignment Model). MaDAM is designed to work with large regional networks because it does not consider vehicles individually but as packages. The propagation of the traffic through the network roads and junctions can be reflected due to variation in demand over time, and the response of traffic to dynamic conditions within the model. Networks at such a large scale as used in these evacuation calculations are too large to be modeled by microscopic assignments (which are based on individual vehicles).

2.3 Static versus dynamic assignment

The static model in the Evacuation Calculator is meant to obtain a quick, less accurate, estimate of the evacuation time. The parameters used in the Evacuation Calculator are chosen in such a way that it may be expected that the calculated times can be realized [11]. Because of the short calculation times it is possible to perform sensitivity analysis on input, parameters and evacuation strategy. For detailed analysis the dynamics of the traffic is taken into account in the MaDAM assignment. In the dynamic assignment the trips from origins to destinations are used that were determined in the static model. Also the same network is used to which same characteristics are added to perform a dynamic assignment (e.g. number of lanes, saturation flow and the speed at maximum capacity).

In most of the scenarios the dynamic assignment gives faster evacuation profiles than the static model when the same parameter settings are used. This is because of the conservative estimation of the average velocity and the choices made of the traffic handling at the exits in the static model. Differences in results depend for example on the considered area, the number of evacuees and the distribution over the area and the traffic management. So there exists no clear link between the static and dynamic results.

Combining the results of the static and dynamic model gives a bandwidth to the possible evacuation time. For each area the results give their own interpretation in possibilities but also in the risks.

3 Evacuation study Program National Safety (PNS)

The Program National Safety (PNS, in Dutch: Programma Nationale Veiligheid (PNV)) is meant to take care for the protection of the society towards internal and external threats. To make this possible, PNS describes a working method that leads to an integral and coherent approach to avoid social disruption. Reason for this method is the need for the Dutch government to obtain better insights in what threats are (and how bad that is) to be able to answer the question if they have the capacities to deal with these situations.

Part of the PNS is to do research with respect to the available capacity of road infrastructure in case of a threatening flood. Therefore a number of scenario s have been calculated with respect to the coastal and river areas in the Netherlands. The effect of several evacuation strategies have been obtained [2].

Up to 4.8 million people have to move to safe areas in case of an evacuation of the Dutch coastal area. This is 29% of the Dutch population, of which 88% is self reliant and 12% is non self reliant [12]. For coastal areas the available time for evacuation is 24 hours (1 day). So many people have to evacuate in very short time. The period of 24 hours for coastal areas is equal to a period 48 hours before dike breach because the last 24 hours will not be available for evacuation because of extreme wind speed. The available time is the period between the moment of decision making for evacuation and the moment of dike breach.

The number of inhabitants in the river area is 1.1 million. The population is split up into 980.000 self reliant and 120.000 non self reliant people. The available time of an evacuation of the river area is 72 hours (3 days) which is longer than for the coastal area. This is because a possible flooding in river areas is better predictable with less uncertainties.

In Figure 1 the threatened coastal area and river area is shown. The river area consists of the Rijn-Maas area together with the Rijn-IJssel area. Because of the size of the coastal area and large corresponding calculation times it was decided to split up this area into 5 less uncorrelated areas based on the possible evacuation routes. The 5 areas are the following:

- I Zeeuws Vlaanderen.
- II rest of province of Zeeland and the islands of South Holland.
- III province of South and North Holland.
- IV province of Fryslân and Groningen.
- V province of Flevoland and surroundings.

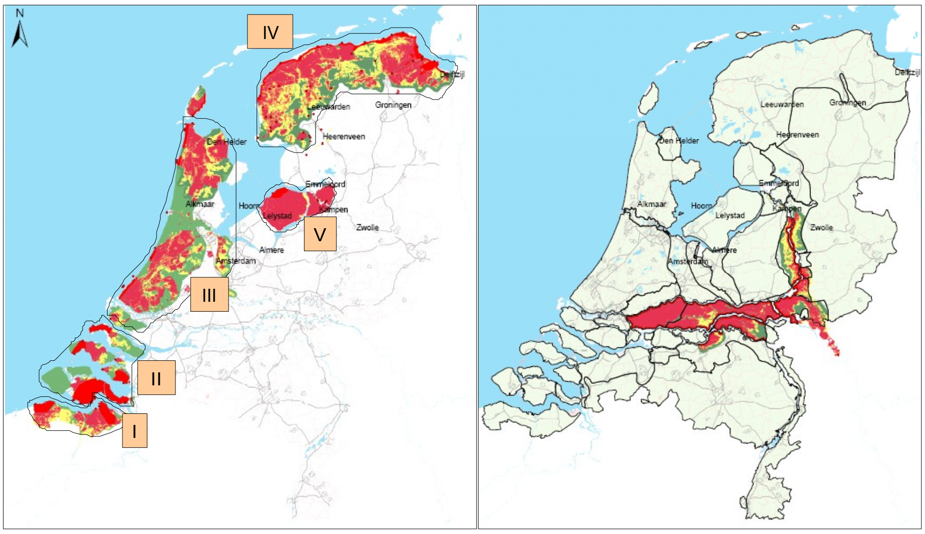

Fig. 1. Threatened coastal and river area in the Netherlands

The high threatened (red and yellow areas) will flood in one of the possible worst credible flood scenarios. The low threatened areas (green areas) can also flood but with lower probability (breaches at other places, internal breaches) and the area in which almost al services (electricity, gas, waste water, drinking water, telephone etc) are assumed to break down.

The five coastal areas may be considered independent of each other because the evacuation routes are all eastwards (except for area IV where the evacuation routes are southwards) and it is therefore not plausible to evacuate via an adjacent threatened area. Because of the assumed independency of the areas some roads are considered not for use during a preventive evacuation, like the Afsluitdijk (between area III and IV) and the dike through the Lake IJssel between Enkhuizen and Lelystad (between area III and V). For each coastal area the network was cut from the Dutch network along the border of the threatened and safe area. By using this smaller network calculation times are reduced. The evacuation route to a reception camp (or relatives) will be longer in practice, but was not considered in these calculations.

In the network the exit points of the coastal areas are defined east of the area (south of the area in case of area IV). The exit points of the river area are defined in all directions except towards the area of the river Lek, which also is threatened. Only highways and provincial roads are defined as exit points. A correction factor equal to 0.2 is applied on all exit capacities to take into account that traffic jams outside the evacuation area will have effect on the capacity of the exit.

In Table 1 the following four evacuation strategies are distinguished. The variables in these strategies are the self reliant and non self reliant people.

Table 1. Evacuation strategies: fractions of population of self reliant and non self reliant that leaves given the risk in the threatened area

	High threatened area		Low threatened area	
	Self Reliant	**Non Self Reliant**	**Self Reliant**	**Non Self Reliant**
Maximum preventive evacuation	Leave	Leave	Leave	Leave
High preventive evacuation	Leave	Leave	Stay	Leave
Low preventive evacuation	Leave	Leave	Stay	Stay
Minimum preventive evacuation	Stay	Leave	Stay	Stay

For all strategies it is assumed that 20% of the self caring people do not follow the instructions of the government. This means that when they are asked to leave the threatened area, this group will stay and otherwise (see Table 2).

Table 2. Evacuation strategies: fractions of population of self reliant and non self reliant that leaves given the risk in the threatened area

	High threatened area		Low threatened area	
	Self Reliant	**Non Self Reliant**	**Self Reliant**	**Non Self Reliant**
Maximum preventive evacuation	0,8	1	0,8	1
High preventive evacuation	0,8	1	0,2	1
Low preventive evacuation	0,8	1	0,2	0
Minimum preventive evacuation	0,2	1	0,2	0

In Table 3 the number of inhabitants that have to be evacuated per area are shown. By multiplying these numbers with the fractions of Table 2 the number of evacuees per evacuation strategy are defined.

Table 3. Number of inhabitants per type of threatened area (x 1.000)

		High threatened area		Low threatened area		
	Number of inhabitants	**Self reliant**	**Non self reliant**	**Self reliant**	**Non self reliant**	**Total**
Coastal area	area I	82	10	15	2	109
	area II	128	16	43	5	193
	area III	1.827	228	1.331	166	3.552
	area IV	363	45	321	40	770
	area V	141	18	0	0	159
	totals coastal area	2.542	318	1.710	214	4.783
River area		758	93	222	27	1.101

In Table 4 the calculated evacuation times are shown for the evacuation of all inhabitants (strategy 1: Maximum preventive evacuation) and the evacuation of only the non self reliant in the high threatened area (strategy 4: Minimum preventive evacuation). It concerns the results for the distribution to the *Nearest exit* and *Traffic management* (both static and dynamic results). The evacuation times are shown in

bold if they are within the norm of 24 hours at the coastal area or 72 hours for the river area. All simulations were stopped after 72 hours.

Table 4. Evacuation times (hours) per area

		Zeeuws Vlaanderen		Zeeland & islands of South-Holland		South-Holland & North-Holland		Flevoland & surrounding areas		Fryslân & Groningen		River area	
	Evacuation strategy	**1**	**4**	**1**	**4**	**1**	**4**	**1**	**4**	**1**	**4**	**1**	**4**
Scenario	Nearest exit, static	**40**	18	**35**	18	**>72**	**>72**	**62**	21	**>72**	**38**	**>72**	45
	Traffic management, static	22	18	23	18	**>72**	24	**26**	18	**33**	21	27	18
	Traffic management, dynamic	18	18	**27**	18	**71**	22	18	18	**36**	18	24	-

The results show that an evacuation of all inhabitants within 24 hours at the coastal area is impossible, apart from the first two smaller areas. Even the evacuation of the non self reliant in the high threatened area (strategy 4) is by far not possible for the province of South and North Holland. The evacuation of the river area within 72 hours is possible. In both areas (coastal and river) is turns out that the road capacity is a limiting factor and a smarter use of the road capacity and a better distribution of the people to the exits results in less evacuation time. The effect of traffic management becomes bigger in case of busier roads and limiting number of exits. The avoidance of crossing traffic flow is essential during an evacuation.

The results of the dynamic calculations give insight in the location of expected bottlenecks. For example at the A13 as is shown by figures in [4]. The expected bottlenecks can be investigated and may lead to local traffic management measures, like managing the inflows at ramp metering or better spreading of evacuees over the evacuation routes.

The results of the calculations learned that the river area had to be split in 2 outflow areas to avoid some undesirable evacuation routes. The reason for this splitting is the shape of the river area which can lead to long unrealistic routes through the area from west to north, because the number of inhabitants in the northern part of the river area is relatively low with respect in combination with available road capacity of A1, A28 and A50. The split is put near the city of Arnhem so that evacuees from the rivers Rijn-Maas and river IJssel are separated.

The effect of disturbances was considered for the area with the biggest consequences (North and South Holland). It was considered what the evacuation will be if only the highways (and not the provincial roads) are available as exit points, which means a reduction of road capacity equal to 50%. As a result in all scenarios the evacuation times increase a lot. It is not possible to evacuate 50% of the people to safe area in 72 hours and it takes longer than 24 hours to evacuate 25%.

In the river area it was also considered what the effect of not using the provincial roads will be. Apart from the strategy *Nearest exit* all evacuation times increase. This can be explained because of the location of settlements near provincial roads which leads to non-optimal usage of the available road capacity in *Nearest exit.* This means that not in all situations usage of less exits leads to deterioration of evacuation times.

4 National Concept Traffic Management (NCTT)

The National Traffic Center together with the regional traffic control centers have developed the National Concept Traffic Management (NCTT). The concept is described below. Several calculations have been performed to understand the impact of the NCTT in terms of evacuation times for different evacuation strategies in case of a threatening flood at the coastal area.

The aim of NCTT is:

- To facilitate the traffic flow from the risk areas to safe areas as good as possible without limiting all other traffic in the Netherlands unnecessarily.
- To keep reliable possibilities for assistance traffic to enter and leave the risk area.
- To be applicable to coast, river, as well as lake scenarios

Description of the NCTT

Evacuation takes place through the main (and logical) trunk roads from the threatened areas to the safe areas. For this purpose the national roads designated as evacuation routes are lifted from the normal network . Therefore highway junctions and connections are mutated to create no or limited exchange of traffic at the highway junctions and connections. The private evacuation traffic will use the normal lanes in the direction west-east. The lanes in the east-west direction will be made available for help assistance, so they can reach and leave the threatened area.

The country is divided in 3 zones:

- Zone 1: threatened area.
- Zone 2: transit zone.
- Zone 3: rest of the Netherlands.

In zone 1 everything is focused on traffic outflow. At highway junctions flows from north to south are completely separated from flows form west to east to avoid disturbances in the outflow. At connections of the highway traffic has to be able to enter the highway to leave the threatened area in the direction of the safe area. The on ramp of the roadway towards the safe area is the only lane open to this connection. The on ramp should be monitored (human ramp metering) to prevent the ramp becoming a bottleneck (Figure 2).

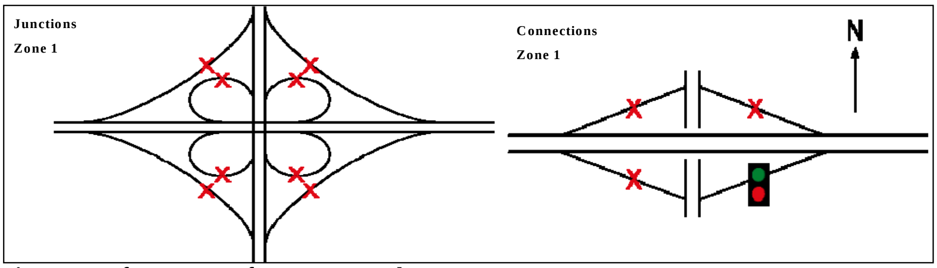

Fig. 2. Configuration of junctions and connections in zone 1

In zone 2 the evacuation traffic has to drive through or go with the least possible problems. Theoretically, cars are allowed to exit the highways in this non-threatened area to encourage the self reliant behavior without stagnating the evacuation flow. Highway junctions are mutated similarly to zone 1. Regular traffic in this area is safe but it may not use the evacuation routes to avoid disturbances in evacuation traffic. It is also not allowed to drive towards the threatened area. Therefore all ramps are closed during the evacuation, except the off ramp eastwards for quiet periods so traffic can exit the highway. This has two advantages:

- The evacuation flow on the highway becomes smaller, which reduces the chance of blocking.
- Evacuees can find a reception place, which illuminates the pressure on the reception camps.

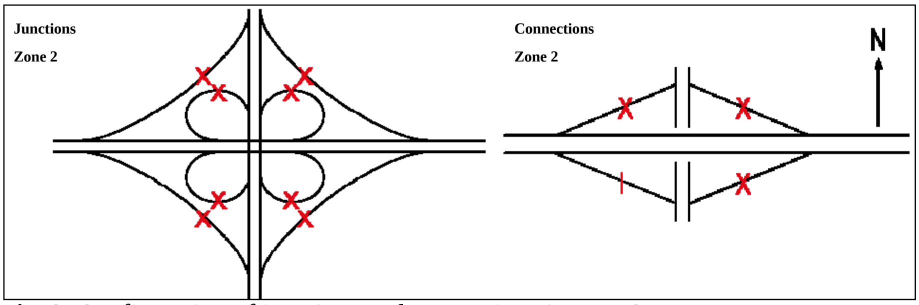

Fig. 3. Configuration of junctions and connections in zone 2

The rest of the Netherlands in zone 3 is far from risk. In this zone free traffic is possible to keep the economic movements in the non-threatened part of the Netherlands going and to ensure that the evacuees can find their preferred destination.

The highway junctions are enclosed in zone 3 for the following reasons:

- Traffic movements towards the west have to be blocked
- North-South flows and an west-east flows should be able to exchange, so that evacuees can drive towards the north or south.

This is however only for the junctions on the border of zone 2 and zone 3. At junctions located further east all traffic flows have to be possible (no mutation).

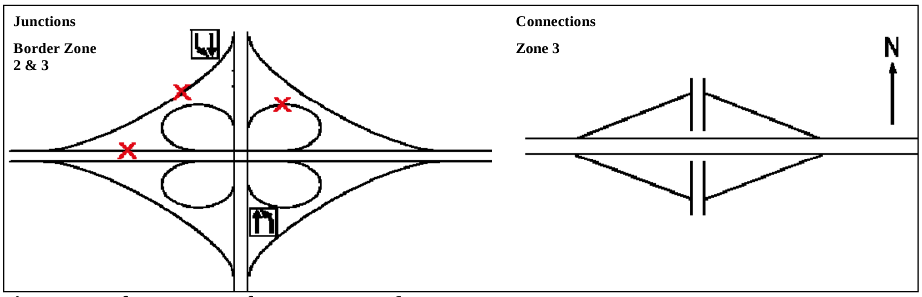

Fig. 4. Configuration of junctions and connections in zone 3

Calculations and analysis

In the application of the NCTT for the coastal area for each safety region it was defined by which evacuation route the evacuees have to reach one of the 12 reception camps (Figure 5). The Netherlands is divided in 25 safety regions, 13 of them belong to the threatened coastal area.

The NCTT concept is defined in the modeling network by excluding the links that may not be used in the path search of the assignment (i.e. arc at junctions and connections according to the concept). The calculations in this study have been done in the total Dutch network, because the concept is at national level and also because the evacuation routes until the reception camps are now considered.

No correction factor is applied on the exit capacities because in these calculations the exits were defined at the reception camps and not at the border of the threatened area.

In NCTT for each safety region it is defined to which reception camps has to be evacuated (Figure 5). This link is based on the experiment Waterproef (November 2008) and insights of the Traffic Control Center and the safety regions. Therefore, in the Evacuation Calculator the option *Outflow areas* is used. It turns out that this definition between origin and destination does not spread the evacuees optimally over to the road capacities. Therefore, also calculations have been done in which the choice from origin to the possible destinations (reception camps) is not defined in advance but determined by the Evacuation Calculator. Especially for the provinces of North and South Holland this gives a better spread of evacuees via the four main highways (A1, A2, A12 and A15). This is called the HIS-EC approach. In Table 5 the evacuation times to the reception camps are shown for both NCTT and HIS-EC (static and dynamic calculations). After three days 85% of the evacuees has arrived in zone 2 in strategy 1 of NCTT and is therefore in theory not threatened anymore.

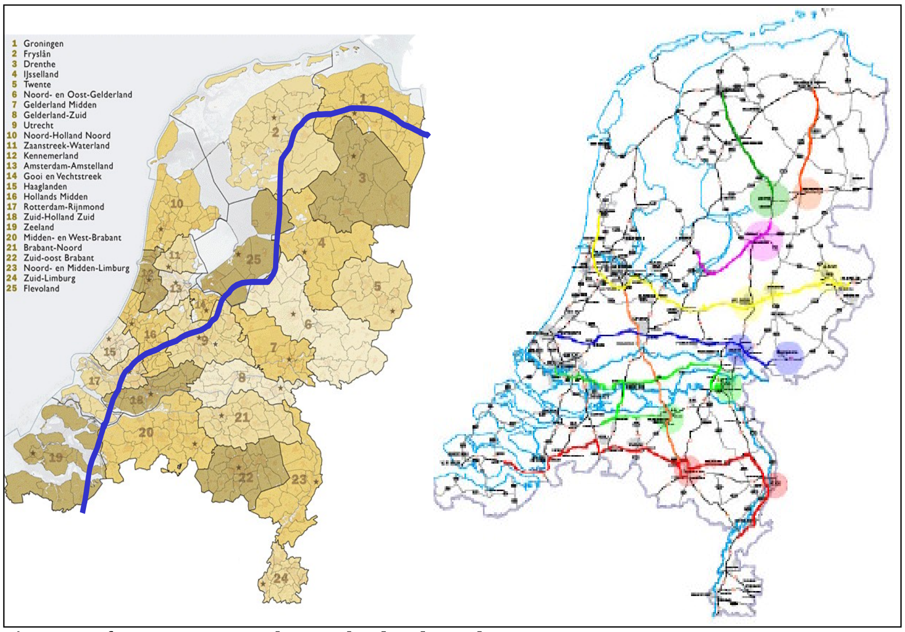

Fig. 5. Safety regions in the Netherlands and evacuation routes in NCTT to reception camps

Table 5. Evacuation times for evacuation strategy 1 and 4 for NCTT and HIS-EC to reception camps

	Static			**Dynamic (border zone 2 en 3)**	
	NCTT		HIS-EC	NCTT	
Evacuation strategy	**1**	**4**	**1**	**1**	**4**
25% evacuated	15	10	15	15	8
50% evacuated	**27**	13	**27**	**31**	12
90% evacuated	**>72**	24	**41**	**>72**	24
100% evacuated	**>72**	**36**	**48**	**>72**	**34**

The total number of inhabitants of the coastal region is 4.8 million people. In strategy 1 (Maximum preventive evacuation) 3.9 million inhabitants are evacuating, the number of evacuees in strategy 4 (Minimum preventive evacuation) is equal to 1.2 million. However, the evacuation time of strategy 4 is not a factor 3 smaller than strategy 1. This means, there is potential in the road capacity but the main question is how it is organized to use this capacity in an efficient way.

The idea of separating flow in north-south direction and west-east direction in NCTT could be optimal in an ideal infrastructural network. However, the highway infrastructure in the Netherlands, like in other countries, is designed with respect to accessibility as the highest priority. Therefore at some junctions the principles of NCTT seem not be logical, e.g. the Prins Clausplein where the A4 and A12 come together and evacuees from the city of Leiden at the A4 in cannot enter A12 in eastern direction or the junction at Heerenveen in the province of Fryslân where evacuees from Sneek or Drachten cannot go in southern direction. Possible local adjustments to the concept have not been considered.

Figure 6 shows with NCTT that the division of traffic over the highways is not optimal. After 3 days the evacuation is still processing at the A12 (with a major bottleneck at the city of Bodegraven where the N11 comes together with the A12) with evacuees from the region of The Hague and Leiden, while the A15 is no longer used after 1 day for evacuees from the region of Rotterdam. So in NCTT the infrastructure is not optimally used because the link between safety regions and reception camps via the prescribed routes does not correspond in a proper way with the available road capacity.

To determine the possible effect of an extra lane (e.g. reverse lane) at the A12 to evacuate the people from region of The Hague and Leiden in NCTT an extra model scenario is calculated. From Table 6 it can be seen that this would be a positive measure, although it should be questioned if this can be realized in practice because the lanes towards the threatened area are reserved for assistance traffic and for the non self reliant. It takes 17 hours less to evacuate 50% of the people and at least 10 hours less for 70% of the people. In total, after three days 91% of the evacuees has arrived in zone 2 in strategy 1 of NCTT with an extra lane at the A12 which is an increase of 6%.

Table 6 Effect of extra lane at A12 in NCTT. Evacuation times from region The Hague and Leiden to safe areas (border of zone 1 and 2).

	A12	A12 with extra lane
25% evacuated	30	21
50% evacuated	**61**	**44**
90% evacuated	**>72**	**63**
100% evacuated	**>72**	**> 72**

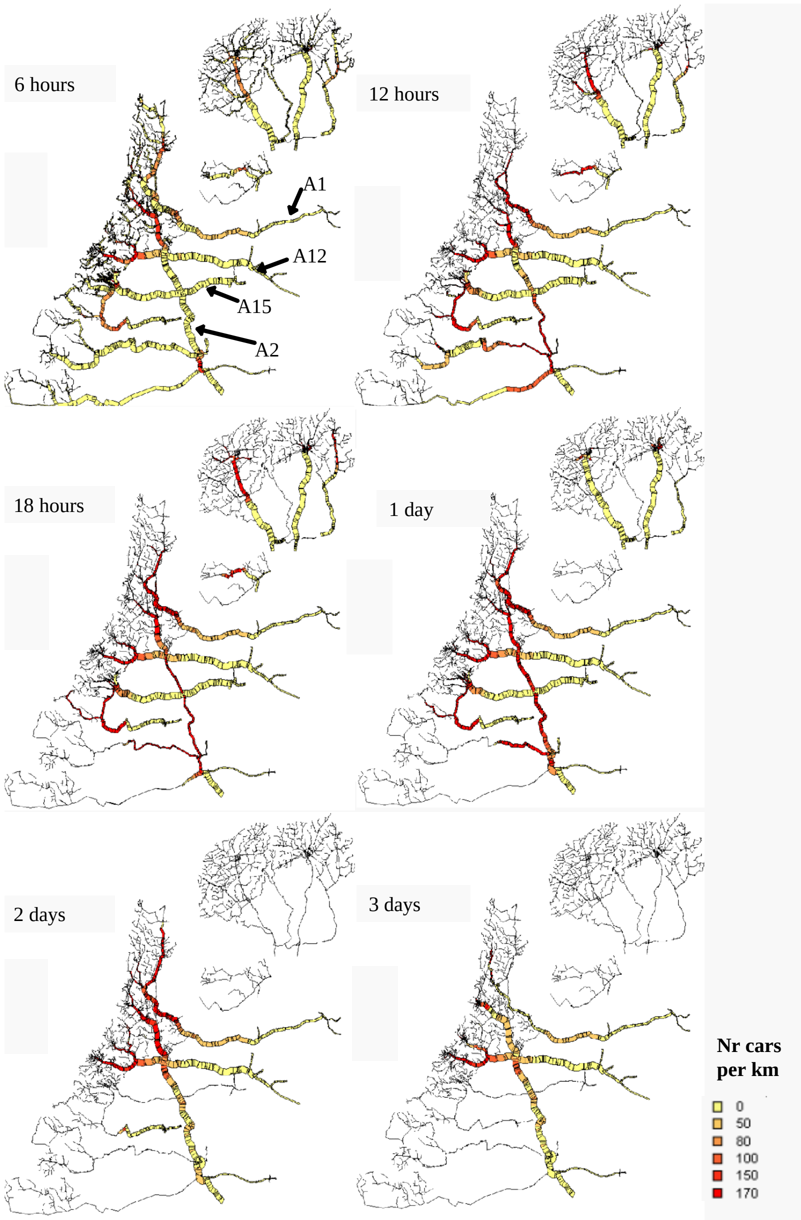

Fig. 6. Evacuation progress in case of the NCTT, strategy 1. The bandwidths present the volumes of the road, the colors represent the density (number of cars per kilometer). Only the infrastructure used is shown

4 Discussion

Based on the experiences of the studies described in the previous chapters hereafter it is discussed in which way improvements in the modeling of evacuation on national scale can be made.

Phasing the evacuation

In the calculations it was assumed that the course of the evacuation process at the origins is the same for all areas. As a result we saw that this may lead to outflow problems for some areas. For example, inhabitants from the city of Haarlem have to pass the city of Amsterdam when evacuating from the coastal region eastwards. At the same time inhabitants from Amsterdam have started evacuating and therefore people from Haarlem get queued at the A9, because the A9 is filled with people from Amsterdam. In this case, it may be preferable to start evacuating the people from Haarlem first for a couple of hours before the people from Amsterdam may start evacuating.

From a traffic point of view this may lead to better results However, it may be questioned if this can be realized in practice. It can also be wondered if phasing is useful if the available evacuation time is only 24 hours. Unless the decision of starting the preventive evacuation can be made earlier.

Research has to be done about the effects of phasing an evacuation with respect to total evacuation time, but also about the practical conditions which is important for the crisis managers: Is it possible in crisis management to regulate a phased evacuation?

Accordingly research has to be done with respect with the departure profile. What will be the effect in the evacuation process if the departure profile is steeper or flatter than is supposed in the calculations (based on experiences of evacuations during hurricanes in the US)? Do more or less bottlenecks occur or at different places in locations or time? And what will this mean for the crisis management? Based on the calculated bottlenecks and the potentials of the network it can be calculated what an optimal departure profile would be.

Smaller units in NCTT

It is possible to optimize NCTT by better distribution of the evacuees to the destinations, as was shown by HIS-EC distribution where no link between origin and destinations was defined. In HIS-EC distribution the mathematical optimum is found based on the fraction of capacities of the roads towards the exit points. Instead of a safety region in NCTT zip-code areas are used in the HIS-EC approach. The question however is if it is practically possible to regulate national evacuation management at the level of zip-codes?

It seems more logical to base NCTT on municipalities instead of safety regions, to keep it possible for crisis managers to have useful communication means but also be able to perform the evacuation in less time. In the search of optimizing the balance over the highway network it has to be kept in mind that it should still be possible for the crisis management to manage the evacuation flows in a proper way.

Optimal use of infrastructure

The calculations have learned that there are possibilities in the network to use the infrastructure in a better optimal way. In the studies performed we did not look at possibilities of using contraflow (e.g. reverse-laning) and the focus was on the highway network. However, the urban and rural roads are at least as important in combination with the access to the highways. It is worthwhile to look at the management of the inflows by human ramp metering to manage the traffic such that the sum of flows of accessing roads keeps smaller than the available road capacity at bottlenecks. For example, does operational traffic management by opening only, say, 4 of the 6 available on ramps help to keep the traffic flows better going? And can this be managed at the rural roads?

Another aspect that can be analyzed are the outflows. What is the effect of not using some of the off ramps? Could this help in the evacuation process and what are the profits in practice?

Other traffic

In the current applications no attention is paid to other traffic. The evacuation calculations start with an empty network, while in reality lots of traffic movements will be made in the threatened area that (e.g. to help each other, to pick up relatives, as a preparation before the real evacuation, etc.) will cause for some problems in the evacuation traffic. Especially during the start of a mass evacuation. Therefore it is interesting to perform some modeling exercises in which other traffic is added to the network. This can be seen as a test of robustness.

Based on data from the Dutch National Accessibility Map in the threatened area it is possible to add other traffic to the evacuation modeling system. The Dutch National Accessibility Map is a model system that contains the traffic at working days for each hour of a working day and is based on the same network and zonal system. First of all research has to be done what percentage of the normal other traffic should be added.

Shelters

It was assumed that all evacuees will leave the threatened area. The results have shown that this will lead to unacceptable evacuation times, mainly in North and South Holland. Shelters within the threatened area can be an outcome. In the evacuation model shelters can be added by defining these location as exit points within the threatened area. The model may show what possibilities and/or risks this may bring. In this situation extra attention has to be paid to the rural network in the threatened area.

5 Conclusions

Based on the 2 modeling exercises with respect to mass evacuation in the Netherlands the following lessons can be learned:

- Usage of transport models is of great value to gain insights in the complexity of evacuation and in understanding effects of possible management strategies.
- Apart from trying to find an optimum in traffic management during preventive evacuation it is important to keep performance of crisis management in mind. The results show there is potential in better use of the road capacities. The challenge for both modelers and crisis managers

is to work out strategies that will give better results but also can be organized in a realistic way.

- In the modeling choices the manipulability of the society can be made perfect, but in reality the perception of people to unknown circumstances like evacuation will be completely different. People will not only respond on governmental information but also in a rational manner on their own perception.
- More road capacity does not automatically lead to less evacuation times. The management of the traffic is of much more importance.
- Many profits in reducing evacuation times can be made by local traffic management. General principles like NCTT can be used as a start and guideline, but will not be the best for local circumstances.

A number of suggestions are given for possible improvements in the transport models to perform more realistic evacuation calculations with respect to the modeling of mass evacuation.

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