Evaluation of the National Concept Traffic Management for Mass Evacuation in the Netherlands

K. Friso, K.M. van Zuilekom, and B. Kolen

***Abstract*—It is impossible to execute a complete and total preventive evacuation of coastal areas in the Netherlands within the available 48-hour time span in case of a storm surge [1,2]. This is mainly due to the limitations of the road capacity in proportion to the number of inhabitants in the threatened area. A flexible triage is proposed to set the target areas and target groups for those circumstances where it is impossible to evacuate all. The routing of all highway traffic (evacuation as well as not-evacuation) was derived from the National Concept Traffic Management (NCTM). In order to reduce the lead-time of the study a mix of static and macroscopic dynamic assignments is used.**

I. Introduction

THE people in The Netherlands live in a delta, which is largely below sea level. Up to 65% of the country, also the area where most of the economic activities take place, is threatened by either sea or rivers. From a historical point of view, the Netherlands has focused primarily on flood prevention, resulting in a flood defence system with the highest safety standards in the world. Floods have become very unlikely but, should they occur, the consequences in terms of casualties and damage would be very substantial. The flood protection system of The Netherlands consists of dikes, dams, storm-surge barriers and dunes. The flood defence has to meet safety standards set by law (the 1996 Flood Protection Act). Despite this safety level, absolute safety cannot be guaranteed.

In 2004 the RIVM showed that The Netherlands is unprepared for a situation of extreme flooding. It also showed that the threat of flooding is one of the largest risks in the Netherlands [3]. The need for further preparation was addressed by the Government [4,5]. Together with the lessons learned from the experiences of Hurricane Katrina in New Orleans, the Dutch Cabinet decided to improve the preparation for flooding [6].

Evacuation is meant to reduce loss of life. With a preventive evacuation, less people will be exposed to danger as they have the opportunity to leave the area before a possible dike breach. Other strategies to prevent loss of life are moving to relatively safe places such as shelters or higher levels.

The Dutch government started a program about public safety in May 2007 [7] which focused on the protection of the overall Dutch society with respect to internal and external risks. Part of the research project has to do with the effects on the possible threat of flooding and the requirements to deal with these types of situations. Risk analyses for The Netherlands in 2008 [8] and 2009 [9] showed flooding to be the disaster type with the most extreme consequences (catastrophic) although the probability is low (highly unlikely).

In this context the Dutch government performed studies on the capabilities of the Dutch road system during different strategies for evacuation, as would be the case under threat of flooding in coastal areas. In this paper the results of these studies are presented and discussed.

The studies focused on the use of traffic management as developed by the Dutch National Traffic Centre and the application of a triage in case of insufficient evacuation time [10]. For storms in coastal areas the path and strength of a storm is difficult to forecast. Complicating is the fact that the last 24 before the storm peak it is unsafe to be on the road. It makes that evacuation could start 48 hours before projected peak, but has to be finished after 24 hours due to extreme wind speed [11]. The time window of opportunity is the period preceding the breach of the dike(s) and the decision on evacuation by government and the public, after detection and realizing the possibility of imminent flooding (described as sense making by Boin et al. [12]).

The forecast period of 48 hours for coastal areas is based on a system of early warning [13,14] and guidelines by, the recently introduced, national commission on flooding [15].

II. National Concept Traffic Management (NCTM)

In as series of workshops the National Traffic Control Center together with the Regional Traffic Control Centers has developed the National Concept Traffic Management (NCTM). This concept tries to use the Dutch highway system in an optimal way during evacuations.

The aim of NCTM is:

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

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 'isolated from the normal network'. Therefore

Manuscript received November 1, 2010.

K. Friso is with Goudappel Coffeng B.V., P.O. Box 161, 7400 AD Deventer, The Netherlands (corresponding author to provide phone: 0570-666812; e-mail: kfriso@goudappel.nl).

K.M. van Zuilekom is with University of Twente, Faculty of Engineering, Center for Transport Studies, P.O. Box 217, 7500 AE Enschede, The Netherlands (e-mail: k.m.vanzuilekom@utwente.nl).

B. Kolen is with HKV Consultants, P.O. Box 2010, 8203 AC Lelystad, The Netherlands (e-mail: b.kolen@hkv.nl).

highway junctions and connections are closed to create no or limited exchange of traffic at the highway junctions and connections. The private evacuation traffic will use the normal lanes eastwards (towards safety). The lanes in the east-west direction are available for assistance traffic, so they can reach and leave the threatened area (see Figure 1).

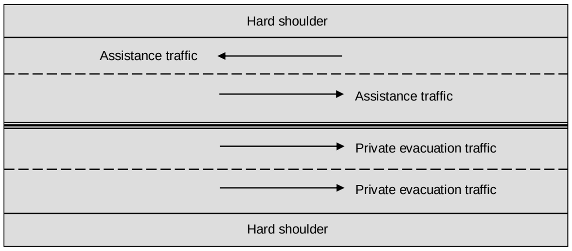

Fig. 1. Classification evacuation routes

Using the northern runway (reverse lane) for evacuation traffic will in theory of course increase the evacuation road capacity but also means a huge extra amount of traffic management needs in guaranteeing the safety of the evacuees and the assistance traffic. Taking the consequences of reverse lanes into account it becomes clear that the efficient use of other roads will be limited. Extra crossings are introduced which will reduce the traffic flow. Based on expert opinion it is concluded that applying reverse lanes on a large scale in the Netherlands will not increase the road capacity for evacuation because of the tight and complex road network and also the limited experience of road users and traffic managers. At the end of chapter IV it is presented what the possible effect would be of a reverse lane on evacuation times. This possible effect is determined by the evacuation model neglecting all practical consequences.

Other modes of transport (like trains or helicopters) for evacuation are not considered here. It is not plausible that trains (and helicopters) will have a significant contribution in the evacuation process [1].

The country is divided in 3 zones: (1) threatened area, (2) transit zone and (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 west to east. In this way disturbances in the outflow are avoided. At highway connections the evacuees have 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 causing or becoming a bottleneck.

In zone 2 the evacuation traffic has to drive through with the least possible disturbance. 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 selective closed 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 of highway connections are closed during the evacuation, except the off ramp eastwards for quiet periods so traffic can exit the highway. The advantage is that the evacuation flow on the highway becomes smaller (which reduces the chance of blocking) and evacuees can find a reception place themselves, which relieves the pressure on the large scale reception camps.

The rest of the Netherlands in zone 3 is far away from the 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.

Specific lanes of 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 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 changes)

NCTM concept is implemented in the modeling network by excluding the links that may not be used in the path search of the assignment (i.e. arcs at junctions and connections according to the concept). No correction factor is applied on the exit capacities in NCTM because the exits are defined at the reception camps and not at the border of the threatened area.

III. MODELING THE NCTM ON A NATIONAL SCALE IN THE NETHERLANDS

As we will see the case study of the coastal storm threat in principle involved quite a computational burden due to the size of the network (> 4000 zones, up to 4.8 million evacuees), four triage strategies and at least two traffic management scenarios. In advance macroscopic dynamic assignment was preferred for its accuracy. But applying this for the whole of the Netherlands was questionable due to extreme runtimes (several days per run) and the available lead-time for this study. For this reason a stepwise approach with a mix of static and dynamic traffic assignment is developed.

The Evacuation Calculator was used for three purposes: (1) calculation of the production (per triage strategy), (2) creation of the OD-matrix (Origin-Destination) per traffic management scenario and (3) an estimate of the evacuation time.

Plots of a static traffic assignment in OmniTRANS were used as a visual check on the correct implementation of the NCTM.

For the most relevant scenarios the macroscopic dynamic assignment of OmniTRANS is used for a better prediction of the evacuation time and in-depth insight in the development of the evacuation in time (particularly at bottlenecks).

A. *Evacuation Calculator*

The Evacuation Calculator is a tool that calculates the traffic production for categories of evacuees. Using four predefined strategies of traffic management it generates the OD-matrix. A full description of the working principles of the Evacuation Calculator is given in [16,17].

By combing a departure profile (which indicates the departures of people over time), the OD-matrix, the distance matrix and assumptions for the capacities of the exit points it can give an estimate of the evacuation time. The OD-matrix can be processed by static macroscopic or macroscopic/microscopic dynamic assignment methods. The user is free in defining socio-economic data, production coefficients, departure profile and capacity of exits. Default settings for the Evacuation Calculator are documented in [18].

The Evacuation Calculator distributes the number of trips for all source zones over the different exits available using one of four strategies for traffic management:

- *Reference:* The evacuees from origin zone are distributed over all possible exit points using user defined weights. This strategy approaches a situation in which no direction is given in the evacuation process. The evacuees choose exits according to its relative weight. As a result, most likely, there will be an imbalance in the amount of evacuees at the exit points, relative many car kilometers will be made inside the threatened area. Crossing flows at crossroads are present. 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 at intersections so that the chance of queues and accidents at intersections will be reduced. However, the capacity of the network will not be used optimal.
- *Traffic management*: Exits are used proportional to their capacity, crossing traffic flows at intersections are avoided and car kilometers are minimized (given proportional use of exits). In this way directed, convergent, non-crossing traffic flows to the exit points are realized. Zones are assigned to one or more exit point, so-called outflow areas. This will reduce one big complex evacuation problem to a number of isolated less complex sub-problems. Knowledge of local circumstances can be reason for modification of these outflow areas. For this reason a forth strategy is available.
- *Outflow areas*: The user may select any part of the area which needs to be evacuated to one or more exit points, so-called outflow areas. Within each outflow area it is guaranteed that the exits for each outflow area are used proportional to their capacity, crossing flows at intersections are avoided and car kilometers are minimized (given proportional use of exits).

As alternative to a distribution dictated by the NCTM concept the *Traffic management* strategy is used.

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 first strategy in the Evacuation Calculator will most certainly trigger the crossing flows whereas the last three strategies avoid crossing traffic flows.

The following modeling 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 in static model runs. Because it is very uncertain of what the progress of traffic in this area will be, it is permitted to use this conservative speed.
- *No disturbances*: It is assumed that during the evacuating process there will be no disturbances that influence traffic, like car accidents, fallen trees etc.
- *Other traffic*: The organization of evacuation assistance and other rescue or help services is not incorporated in the model.
- *Empty network*: The road network is supposed to be empty at the beginning of the preventive evacuation. 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 non self reliant people. It is assumed that 80% of the self reliant [1] will evacuate by car with on average 2.26 persons per car [19] (441 cars per 1000 inhabitants in 2007). 20% of the self reliant people will evacuate by bus with an average capacity of 25 persons [1]. The non self reliant people will be evacuated by different means of vehicles (on average 5 persons per vehicle).

B. *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 static assignment. Therefore, for some interesting scenarios, the modeling of congestion dynamics using dynamic assignments was 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).

IV. Case Studies

Different risk zones have been distinguished for the coastal area in the Netherlands because of a storm surge thah might cause a worst credible flood (shown in Figure 2). The threatened area is a combination of all possible flooding events in case of the storm surge. The high threatened (red areas with possible water depths of more then one meter and yellow areas with lower water depths) is most likely to 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.

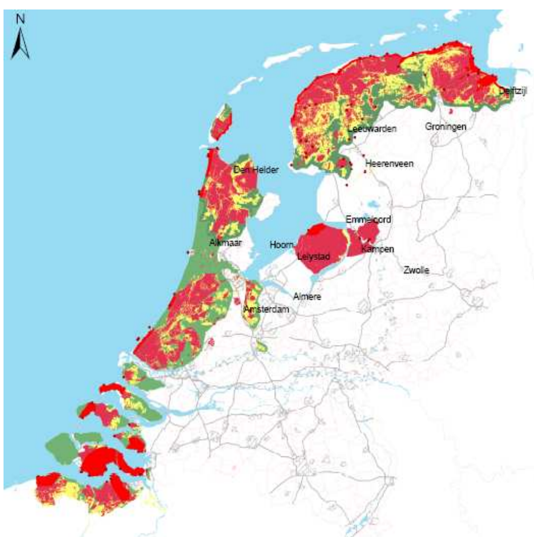

Fig. 2. Threatened coastal area in the Netherlands

In Table 1 four evacuation strategies are distinguished. The variables in these strategies are the level of threat for the area and categorizing people by self reliant and non self reliant.

TABLE I
TRIAGE STRATEGIES

	High threatened area		Low threatened area	
Preventive strategy	Self Reliant	Non Self Reliant	Self Reliant	Non Self Reliant
1 Maximum	Leave	Leave	Leave	Leave
2 High	Leave	Leave	Stay	Leave
3 Low	Leave	Leave	Stay	Stay
4 Minimum	Stay	Leave	Stay	Stay

For all strategies it is assumed that 20% of the self reliant 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). Non self reliant people do not have a choice and will all leave or stay depending on the strategy.

TABLE II
TRIAGE 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	
Preventive strategy	Self Reliant	Non Self Reliant	Self Reliant	Non Self Reliant
1 Maximum	80%	100%	80%	100%
2 High	80%	100%	20%	100%
3 Low	80%	100%	20%	0%
4 Minimum	20%	100%	20%	0%

Up to 4.8 million people (29% of the Dutch population) have to move from the threatened area to safe areas in case of an evacuation of the Dutch coastal area because of a storm surge as a worst credible flood, of which 88% is assumed to be self reliant and 12% is non self reliant [20]. For the coastal area the available time for evacuation is 24 hours (as stated in the introduction). So many people have to evacuate in very short time.

The NCTM-concept is applied for the coastal area on the level of safety regions. The Netherlands is divided in 25 safety regions, 13 of them belong to the threatened coastal area (see Figure 3). For each safety region it is defined to which reception camps has to be evacuated and by which route, based on the experiment *Waterproef* (November 2008) and insights of the Traffic Control Center and the safety regions.

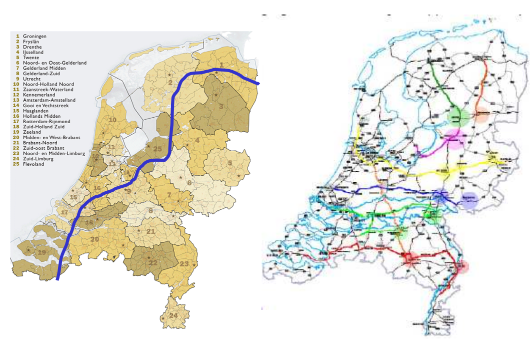

Fig. 3. Safety regions in the Netherlands and evacuation routes to reception camps in NCTM

Results of NCTM show that the division of traffic over the highways is not optimal (see figures in [21]). 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. The main obstacles can be found in the throughput of evacuees from zone 2 to zone 3. So in NCTM 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. Therefore, a model run is performed in which the choice from origin to a possible destination (reception camp) is not defined in advance but determined by the Evacuation Calculator using the *Traffic management* option and small zip-code areas instead of the safety regions. 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).

In Table 3 the evacuation times to the reception camps are shown for both NCTM and HIS-EC 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). The evacuation times are shown in **bold** if they exceed the norm of 24 hours (the total available 48 hours are reduced by 24 hours because of the period with extreme wind speed before the possible dike breaches). All simulations were stopped after 72 hours. After three days 85% of the evacuees has arrived in zone 2 in strategy 1 of NCTM and is therefore in theory not threatened anymore.

TABLE III
EVACUATION TIMES (HOURS) TO RECEPTION CAMPS (NCTM AND HIS-EC)

	NCTM-static		HIS-EC static	NCTM-dynamic (to border of zone 2 and 3)	
Preventive 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**

It can be concluded that is not possible to perform a total evacuation in 24 hours for both strategy 1 and 4. Disturbances in such a complex process will only lead to worse situations. If the focus is on not evacuating the self reliant evacuees (strategy 4) then the evacuation times decrease. 90% of the non-self reliant can be evacuated from the threatened area within one day.

The biggest problems during evacuation will occur in the provinces of North Holland and South Holland. For some parts of the coastal area it seems possible to perform a total evacuation of strategy 4 in 24 hours, e.g. province of Groningen, Fryslân and Zeeland, Rotterdam Rijnmond and IJsselland and Flevoland. In all cases it is assumed that no disturbances will take place during evacuation.

The idea of separating flow in north-south direction and west-east direction in NCTM 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 highway junctions the ideas of NCTM seem not be logical, e.g. the Prins Clausplein near The Hague.

An extra lane (e.g. reverse lane) at the A12 to evacuate the people from region of The Hague and Leiden in NCTM means a reduction of 17 hours to evacuate 50% of the people and at least 10 hours less for 70% of the people. However, 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.

V. DISCUSSION AND CONCLUSIONS

A transport model is of great value to gain insights in the complexity of evacuation and in understanding effects of possible crisis management strategies. The challenge for both modelers and crisis managers is to work out strategies that will give better results but also can be organized and effective in reality. A fixed link between origin and reception camp, as is used in NCTM, creates a stable situation which is important in defining an evacuation plan (e.g. communication plan) where many agencies are involved. The results show that good preparation to make maximum use of the road network in case a crisis is of major importance. It also has to be kept in mind that people will not only respond on governmental information but also in a rational manner on their own perception [22].

Some suggestions for improvements in the modeling of evacuation on national scale are the following.

A. 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. This may lead to outflow problems for some areas. E.g. inhabitants of Haarlem have to pass Amsterdam when evacuating eastwards. Now, at the same time inhabitants from Amsterdam have started evacuating and therefore people from Haarlem get queued at the A9. From a traffic point of view it may lead to better results if people from Haarlem may start evacuating at first. However, it may be questioned if this can be realized in practice. Is it possible in crisis management taken citizen response into account to regulate a phased evacuation in such a mass event? Also research has to be done with respect with the departure profile regarding the perception of the threat at a specific moment.

B. Use of infrastructure

The results show that possibilities exist to use the infrastructure in a better way. Main focus in the case studies is on the highway network. However, urban and rural roads have a significant importance in combination with the access to 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. But can this be managed at the rural roads?

C. Other traffic

In the case studies no attention is paid to other traffic because of measures taken by crisis managers (and assumed to be effective) based on the actual threat. The 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.) which will cause for extra 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 and define the consequences. Data from the Dutch National Accessibility Map can be used in this case.

D. Shelters

The results show that evacuating all evacuees leads to unacceptable evacuation times, mainly in North and South Holland. Shelters within the threatened area can be an outcome to further decrease loss of life. In the evacuation model shelters can be added by defining these location as exit points within the threatened area. Using shelters as a plan B further more adaptive evacuation planning can be developed. If a preventive evacuation (plan A) is not possible any more people can fall back on plan B at any time.

E. Assignment of area's to exits

It is possible to optimize the NCTM concept by a better distribution of the evacuees to the destinations, as was shown by HIS-EC using the *Traffic management* option and areas based on zip-codes (instead of the much larger safety regions). In *Waterproef* the question arose to what extent it is possible to communicate and coordinate more or less sophisticated evacuation management? The results indicate that pragmatic choices made in development of the NCTM lead to results which are far from optimal. A balance is needed between a modeled result versus a controllable, robust and sound concept from a traffic manager point of view. The by the modelers suggested simple changes with significant improvement were rejected by the National Traffic Control Center as being too complicated to organize in practice. It shows that building bridges between science and practice is essential before balancing is possible.

REFERENCES

[1] Ministry of the Interior and Kingdom Relations, Ministry of Transport Public Works and Water Management, "*Capacity analysis for the task large-scale evacuation. Report National Security"* (in Dutch). The Hague, 2008.

[2] Kolen, B., Helsloot, I.: "Time needed to evacuate the Netherlands in the event of large-scale flooding: strategies and consequences", Journal of Disaster Studies, Policy & Management (Submitted).

[3] ten Brinke, W.B.M., Bannink, B.A., Ligtvoet, W., "The evaluation of flood risk policy in The Netherlands", *Journal on Watermanagement*, vol. 151, nr. 4, pp. 181-188, 2008.

[4] Ministry of the Interior and Kingdom Relations, "*Ministry of Transport, Public Works and Water Management: Strategies for flood disaster control along the rivers Rhine and Meuse*" (in Dutch), The Hague, 2005.

[5] Ministry of the Interior and Kingdom Relations, Ministry of Transport, Public Works and Water Management, "*Cabinet standpoint disaster management floods*" (in Dutch), The Hague, 2006.

[6] Remkes, J., "Decision implementing 'Taskforce Management Flooding' " (in Dutch), *Staatscourant*, nr. 241, 2006.

[7] (PNV), "*Program National Security: National Security, Strategy*", (in Dutch), Ministry of the interior and kingdom relations, The Hague, 2007.

[8] (BZK), Ministry of the Interior and Kingdom relations, "*National Security, National risk assessment 2008*" (in Dutch), Ministry of the Interior and Kingdom relations, The Hague, 2008.

[9] (BZK), Ministry of the Interior and Kingdom relations, "*National Security, National risk assessment 2009*" (in Dutch), Ministry of the Interior and Kingdom relations, The Hague, 2009.

[10] Wegh, E., "*National Concept Traffic Management for exercise Waterproef*" (in Dutch), Ministry of Transport, Public Works and Water Management, Utrecht, 2008.

[11] ten Brinke, W.B.M., Kolen, B., Dollee, A., van Waveren, H., Wouters, C.A.H.: "Contingency planning for large-scale floods in the Netherlands", Journal of Contingencies and Crisis Management, vol. 18, nr. 1, 2010.

[12] Boin, A., 't Hart, P., Stern, E., Sundelius, B., "*The politics of crisis management. Public leadership under pressure*", Cambridge, UK, 2005.

[13] Barendregt, A., van Noortwijk, J.M., van der Doef, M., Holterman, S.R.: "Determining the time available for evacuation of a dike-ring area by expert judgment", Conference: ISSH - Stochastic Hydraulics 2005 (proceeding), Nijmegen, 2005.

[14] Jonkman, S.N., "*Loss of life estimation in Flood' risk assessment. Theory and applications*", PhD Thesis, Delft University of Technology. Delft University, Delft, 2007.

[15] Ministry of Transport, Public Works and Water Management, "*Emergency plan "Extreme water level and storm surge". Guideline for a national approach*", (in Dutch), The Hague, 2008.

[16] Zuilekom K.M. van., Zuidgeest M.H.P., "A decision support system for the preventive evacuation of people in a dike-ring area", in *Geospatial Information Technology for Emergency Response*; pp. 329-350, Taylor & Francis Group, London, UK, 2008.

[17] Zuilekom, K.M. van, Maarseveen, M.F.A.M. van, Doef, M.R. van, "A Decision Support System for preventive evacuation of people", in *Geo-information for disaster management*, P. Zlatanova Van Oosterom, S. Fendel, E. M. (eds.) pp. 229-253, Springer, Berlin Heidelberg, 2005.

[18] Doef van der M., Cappendijk P., "*Veiligheid Nederland in kaart: modellering en analyse van evacuatie*", Rijkswaterstaat, 2006.

[19] www.cbs.nl

[20] Kok, M., Huizinga, H.J., Vrouwenvelder, A.C.W.M., Braak, W.E.W., "*Standard method 2005 damage and victims as a result of flooding*", HKV lijn in water (in Dutch), 2005.

[21] Friso K., Zuilekom K.M. van, Kolen B., Holterman S., "*If things do go wrong: lessons learned concerning traffic management during mass evacuation in case of posssible extreme flooding in The Netherlands*", International conference on evacuation modeling and management (ICEM), Delft, 2009.

[22] Helsloot, I., Ruitenberg, A., "*Citizen response to disaster; a review of literature and some applications*", Journal on Contingencies and Crisis Management, vol. 12, nr. 3, pp. 98-111, 2004.