Simulating Traffic Processes for Practicing Large Scale Evacuation

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ABSTRACT

The main goal of disaster management is to reduce the number of casualties to a minimum. Evacuation is one of the means to reduce the number of casualties. This requires efficient and well coordinated activities by many authorities. In preparation of a large scale evacuation the training of authorities and rescue workers is needed. The aim of such practicing sessions is to improve the quality and speed of decision making and increase the level coordination.

A simulation tool, SPOEL, is developed to include the traffic process, the resource planning and the progress of the disaster in one virtual world. This simulation tool supports the supervisors of the training session in giving a realistic feedback. The simulation tool gives insight in the status of the traffic system in general, the progress of the evacuation, the status of (critical) resources, the disaster and casualties.

1 Introduction

Organising large scale evacuations due to a possible flooding is a challenging task. There is only limited time for decision making and the scale of the operation requires a lot of resources (people and material). Preparing for evacuation and training of officials for this situation is very important. Not only for rescue workers but also for the authorities who are responsible for an efficient and effective evacuation.

This paper focuses on the development of a supporting instrument for evacuation training. It helps the authorities to gain insight in the scale of the traffic problems that they face during an evacuation. The instrument also keeps track of the required (scarce) resources during the evacuation, such as helicopters, ambulances, buses, etc.

During a calamity, such as a possible flooding, authorities have to cope with limited, incomplete or perhaps wrong information. A collaboration of many different parties, such as the central government, local government, the police, the fire department and the army, has to make decisions and perform all sorts of tasks. During the evacuation the situation changes continuously and new decisions and actions need to be taken. Altogether, a highly dynamic situation occurs where many professionals are involved and decisions need to be taken at different levels, from strategic down to tactical and operational.

In the setup of a training session this dynamic situation is mimicked. Because a real flooding and evacuation cannot be practiced, the whole situation is simulated. The responsible decision makers do not have direct access to the simulation, but communicate through a so called "response cell". This response cell consists of a group of professionals which provide information to the decision makers in a similar manner as they would do in a real evacuation.

The response cell uses the simulation tool in order to provide realistic feedback on the status of traffic situation, the availability of resources, the status of resources and more or less autonomous developments such as the public opinion, weather, water levels and the state of the dikes. The decision makers will experience the exercise as close as possible to real circumstances. They will use the existing protocols for utilizing equipment. In line with this, the response cell will use the normal communication protocols as much as possible. The decision process is also logged for evaluation purpose.

The dynamics of the traffic system and the resource planning are usually not part of a training session. In reality, however, the traffic situation and the resource management are crucial aspects of a large evacuation. The complexity of the traffic system and the administrative burden of resource management makes the simulation of these necessary.

The Dutch knowledge impulse program 'Living with Water' [1] stimulates collaboration between the domains of water management and spatial planning, science and practice, economy and sociology, both at home and abroad. In an international project consortium collaboration is sought on achieving changes in water management. These changes are required, because traditional water management methods are reaching their limits and technical measures alone are insufficient. Practical experiments bring these different disciplines together, amassing new knowledge and experience. The developing knowledge on large scale evacuation is addressed in the research program '*Van dreigend hoogwater tot en met evacueren*' (From threatening flooding up to and including evacuation) [2,]. One of the topics in this program is the development of a simulation tool, SPOEL, which could support the response cell in creating challenging training sessions for calamities where the dynamics of the traffic system and resource planning play a critical role. SPOEL stands for '*Simulatie Pakket Oefenen Evacuatie Logistiek*' (simulation package for practicing evacuation and logistics). A consortium of several institutions co-financed and co-developed[1].

2 Objective

A training session for planning during disasters evacuation is needed is a very specific educational setting. In general the following questions are leading in developing courses [3]:

- What should the student know after having followed the course? This sets the goal and end situation.
- What are the qualifications of the students? This determines the begin situation.
- How can the gap between begin and end situation be bridged? This sets the teaching program, order of activities, media, etcetera.
- How is determined that the goal is achieved? This sets the exam.

The educational setting for disaster management is however complex, not to compare with the stereotype classroom environment of high school or university.

In these types of training sessions the goals are manifold. There are goals to define for individuals, for teams in an organisation, the organisation as a whole, the cooperation of organisations, etcetera.

In general the participants are professionals with years of experience. There will be a variety of background and qualifications, from generalist to specialist.

A training session has a focus on the application of theory and skills in a complex and dynamic environment with many parties involved with perhaps conflicting interests. In a teaching program a training session is the final stage. Knowledge and skills are taught, trained and tested first as singular modules. In the training session all this comes together in a save environment to practice and test.

The situation is so complex that is not always easy, or even possible, to define what the best decision or the best behaviour is. Even for the experts. Although the

[1] HKV Lijn in Water, Institute for Safety Security and Crisis Management, University of Twente, Fire department Amsterdam Amstelland, Safety Region Utrecht, Water board Delfland, Province of Utrecht, Province of South-Holland, Ministry of Transport, Public Works and Water Management, Ministry of the Interior and Kindom Relations, Impact-knowledge center, Foundation for Applied Water Research, OmniTRANS International, Foundation Living with Water.

egress time and number of casualties are measurable outcomes, but it is not always easy to identify which chain of decisions would improve result.

The aim of the support tool is to include the dynamics of the traffic system and the resource planning in training sessions. The goal is to create an educational support tool which realistically calculates changing environment as a result of autonomous developments and interventions by the authorities. In doing so, it simulates the changing situation of a virtual disaster, which is assumed to be comparable with a real disaster. The support tool should at least deliver the main indicators for the quality of the disaster management: the progress of the evacuation in time and the number of casualties.

3 Program of requirements

In cooperation with the partners in the project the program of requirements is defined. The key elements in the program of requirements were:

- The tool is not visible for the participants in the training situation. It supports the response cell in giving consistent and objective feedback to the participants. This within the usual time frame of a training session.
- For the participants the training sessions should remain more or less the same. The only difference should be an improved feedback on the traffic situation and state of resources.
- The participants should be free to take any decision. The existence of a support tool for the response cell should not be of influence.
- The tool integrates development of the threat (typical flooding or a fire), the traffic situation in the network in time as well as the actual location and status of resource (typical ambulances, equipment or personnel with specific skills).

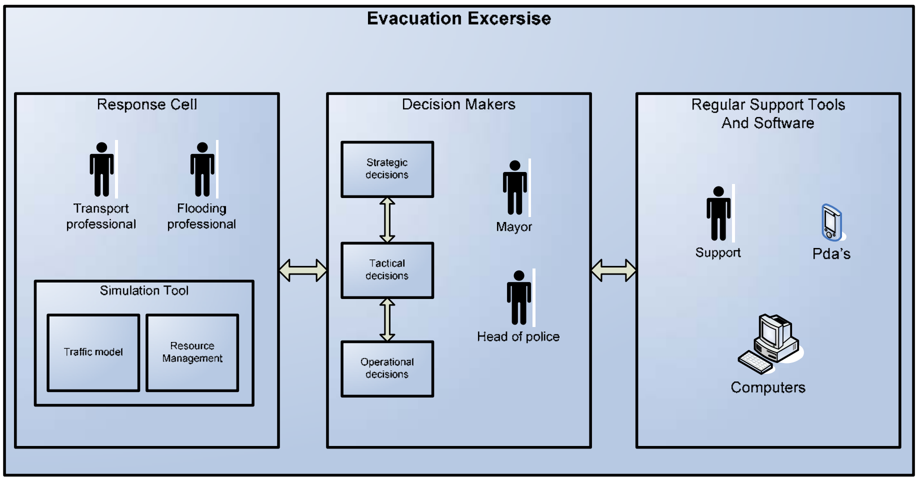

Figure 1 Conceptual model of a training session with the supporting traffic model [6]

An important aspect of the training session is that, on forehand, the decisions and timing of the participants is not known in advance. Imperfect information, imperfect knowledge, negotiations, personal preferences and group dynamics are causing unforeseeable outcomes. As a result, the tool should, in principle, be capable of incorporating any decision that may be relevant for the traffic process and the resource management at any moment in the training.

The stress which evacuees might experience will influence the power of judgement and (driving) skills. For this reason the response cell should be able to include deviations in response.

For evaluations it is necessary that the whole simulation can be 'replayed'. In this way, participants may gather insight in what went wrong or right. Restarting of the training at a given moment in the simulation should give the opportunity to perform 'what if?' analysis. For instance: to try a possibly better approach in case of a mistake or in case of the failure of another dike.

4 Approach

A large scale evacuation is a circumstance in which there is a very specific match of traffic demand and supply. The aim of the authorities will be to influence the circumstances in such a way that as much as possible evacuees will be safe in time. This in an urgent situation where there is limited time for preparation and probably a shortage of means to control the match between traffic demand and supply.

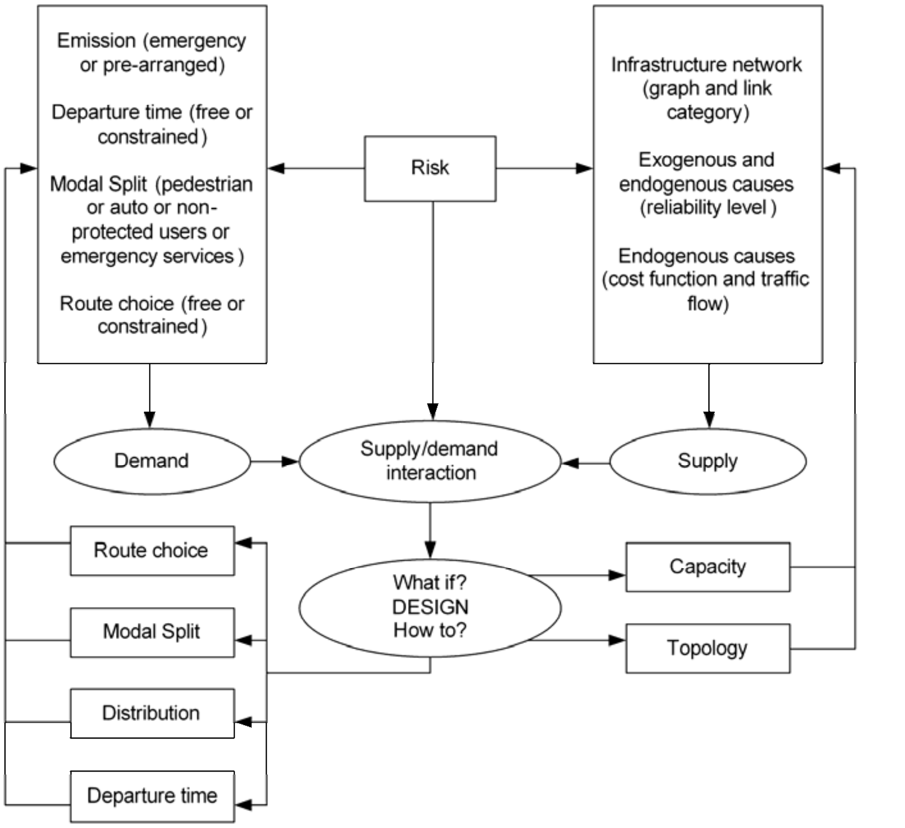

Figure 2 Matching supply and demand in situation of a risk [4]

Following this concept (Figure 2) it is possible to change the demand side by influencing: (1) the number of evacuees, (2) the time of departure, (3) the mode of travel, (4) the destination and (5) the route.

The supply side could be changed by: (1) excluding or including roads, (2) change of the configuration of roads, (3) the use of inbound roads (contra flow) for evacuation traffic and (4) extra traffic management on bottlenecks such as crossings and on/off ramps.

Participants in a training setting are not all familiar with the concept of matching traffic demand and supply. For rescue services responsibilities, tasks and procedures are a starting point in handling a crisis situation. A framework for a joint operation with fire department, medical aid, police and municipalities is used as a basis for analysis (Table 1).

Table 1 The core processes for rescue workers [5]

Combat of source and effect	**Medical assistance**	**Legal order and traffic**	**Care for population**
Fire department (regional commander)	*Medical aid at Accidents and Disasters (regional medical officer)*	*Police (Chief officer)*	*Municipality (Mayor)*
(1) Fire fighting and fighting hazardous chemicals	(9) urgent medical aid	(12) clearance and evacuation	(19) providing information
(2) Saving people and technical assistance	(10) public health protection in case of accidents and disasters	(13) blocking and protection	(20) shelter and care
(3) disinfection of man and animal	(11) psychosocial aid in case of accidents and disasters	(14) traffic management	(21) burial
(4) checking disinfection and organisation of disinfection of vehicles		(15) identifying victims	(22) registration of victims
(5) observation and measuring (as well as water management)		(16) guiding	(23) first necessities of life
(6) warning of people		(17) criminal investigation	(24) registration of damage
(7) making accessible and passable		(18) maintain law and order	(25) environmental car
(8) alarming executives and professionals			(26) after care

The aim in the development of the support tool was to bridge these two worlds. Analysis of the processes (Table 1) made clear that some of these processes had no, or limited, influence on the state of traffic situation or resource management. Although some processes had a specific influence on traffic supply or demand, all the element of the supply-demand were influenced by one ore more process. This insight made the partners in the project decide that the support tool should include all elements of the supply-demand model. The response cell should decide if, where, and to what extend the traffic process will be influenced.

For the resource planning, it had been decided to restrict this to critical resources such as specific vehicles and teams of specialists. The support tool should keep track of location and task of the resources as well of the time it takes for a resource to be relocated.

5 Solution

On the basis of the program of requirements and the concept of a traffic model, which has all aspects of the supply-demand model, an application has been designed. Here we will describe the main elements of the support tool.

The response cell will decide if, where and to which extent decisions and activities of the participants will influence the traffic process. The smallest time step for changing the traffic conditions is one hour[2]. Every hour can be used for a re-run of the simulation.

The traffic model had to fulfil the following criteria: accurate description of the traffic flows in time, sufficient large network size and short runtimes. Static modelling techniques were rejected due to lack of the time dimension. A microscopic traffic model, although very rich detailed, was rejected because of the long runtimes, the extensive preparation and testing of the network as well as limitations in the size of the networks. The dynamic macroscopic traffic model of OmniTRANS International (MaDAM) [7] was chosen as a balanced compromise between the three primary criteria.

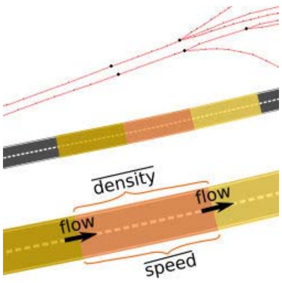

Figure 3 Segmentation of links in MaDAM

To compute the traffic flows at a link MaDAM uses the general flow theory. Each link is automatically divided into several segments (Figure 3). The length of a segment is minimized by the free flow speed (meters/second) multiplied by the time step. For each segment, and each time step, the traffic state is computed. This traffic state depends on both the amount of traffic at the segment and the situation upstream and downstream. MaDAM can differentiate between highways and urban areas and therefore can apply the traffic modelling principle to both classes of links.

For each segment the variables density, flow and speed are determined. Traffic flows on a link can in general be described by the so called 'fundamental diagram'. For MaDAM, the four-parameter single regime model is implemented [8].

[2] In the Dutch circumstances the first indication of a possible flooding due to a storm or heavy rainfall will be in a range from two to five days. The evacuation take could up to three days.

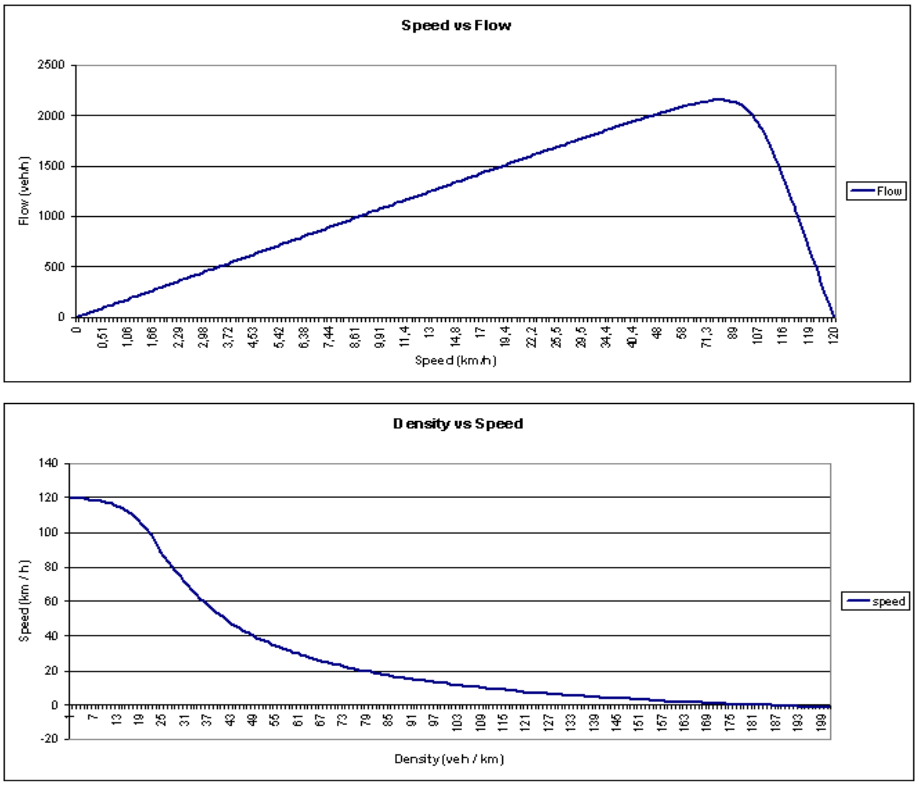

Figure 4 Example of Speed-Flow and Density-Speed relationship in MaDAM

The density-speed diagram (Figure 4) shows the relationship between an increasing density and a decreasing speed. This relationship can be transformed into a speed-flow-relationship which shows the speed according to a specific flow.

The response cell support tool is designed as an internet based client-server application with the following characteristics (Figure 5):

- Several clients, each with a specific role, can prepare changes in the stages of the traffic model. When the model run is finished the clients can view the model results.
- A client server with three primary tasks: (1) keeping track of the changes proposed by the clients; (2) activate the OmniTRANS server to run the traffic model with the changed model stetting and (3) collect the model results and make these available for the clients.
- An OmniTRANS server runs the traffic model on the basis of last model result and the changes proposed by the clients.

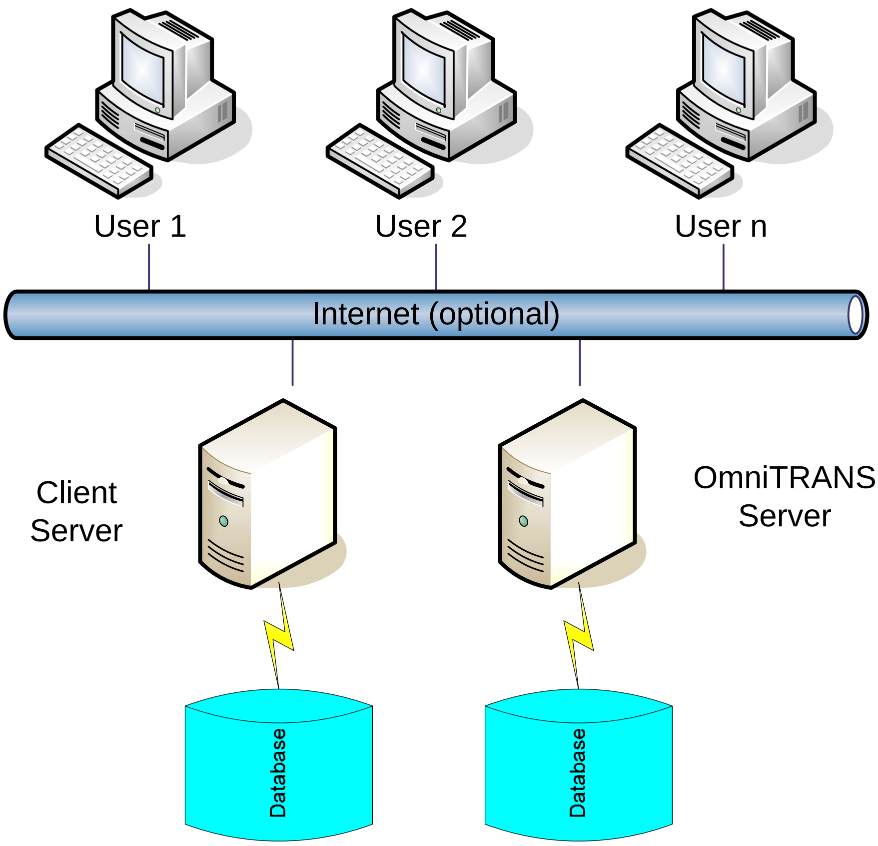

Figure 5 Client-Server architecture

Depending on the demands of the training setting the configuration is scalable from a standalone configuration (one PC with all software operated by one person) to a multi server-multi client configuration (several clients, a client server and an OmniTRANS server).

6 Running the application: preparation and hourly steps

6.1 Preparations before a training session

To avoid laborious data gathering a complete traffic model of the Netherlands is used as a basis (Figure 6) [9]. The model includes: a zonal system, socioeconomic data for the zonal system, a network and (optional) OD-matrices for each hour of a weekday.

To limit runtime and data transfer a subarea is defined as the basis for the training session. The corresponding network, socioeconomic data and OD-matrices are extracted for this subarea. For the training session, specific information could be added, such as: the endangered area, other socioeconomic data and the destinations (exits) for the evacuees. Per zone and per category of evacuee, the number of endangered people is calculated. For each category of evacuees the people-PCU (Passenger Car Unit) relation is set.

Temporary roads which could be added by the participants are included, but initially labelled as ‘closed road’.

The shape data of the traffic model are transferred to the client server together with the socioeconomic data.

Figure 6 Base network for the Netherlands [Ministry of Transport, Public Works and Water Management, 2006]

6.2 Modeling steps per hour

During the training session the participants perform a cycle of: (1) gathering information of the current status of the situation; (2) analysis of the situation and (3) performing actions (Figure 7).

Although it is possible to perform this cycle for each hour, it is likely that the participants will make decisions for the next hours. The response cell will decide what the decision horizon will be. If the dynamics of the event are high at a certain stage, the horizon needs to be short.

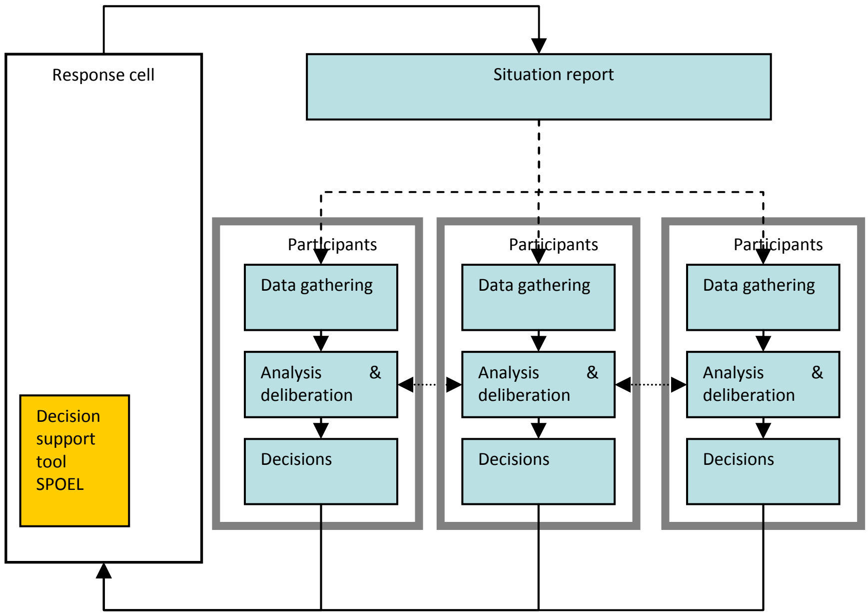

Figure 7 The decision cycle

Each hour the following modeling steps are performed:

- Network changes
- State of the background traffic
- Departure of evacuees
- Destinations for evacuees
- Calculation of the evacuee OD-matrix
- Macroscopic Dynamic Traffic Assignment
- Calculation of the travel times between zones.

In the following sections we will describe these modeling stages.

Network changes

Two types of link changes are possible: (1) global changes applicable for all links and (2) changes for a specific link.

For each hour any link attribute can be changed. This is done by use of traffic controls. A traffic control overrides the attributes of a link for a specified time interval (from start time till end time).

These controls allow the, temporarily, change of link attributes such as speed, saturation flow or the number of lanes, during the simulation.

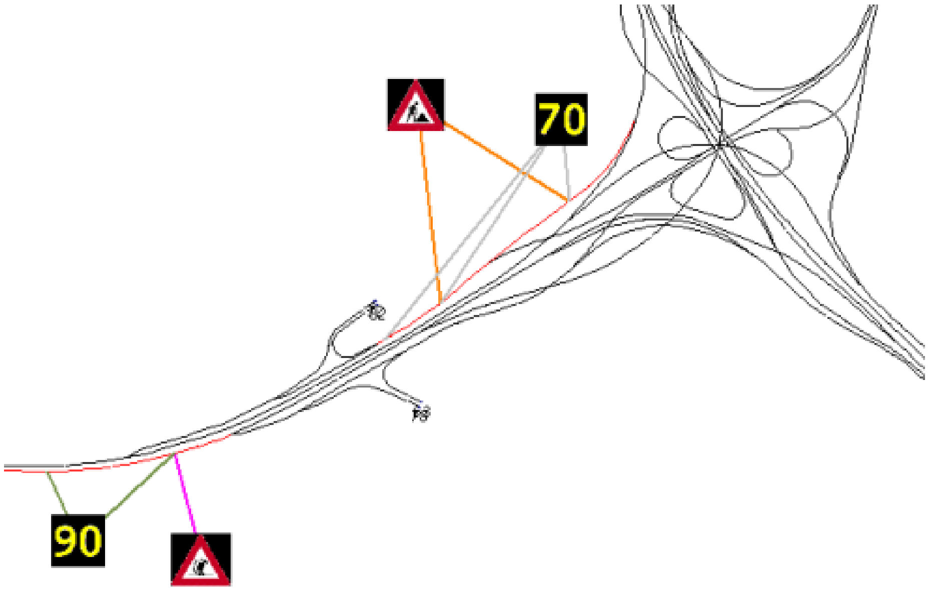

Figure 8 Examples of use of the traffic control

For example for a simulation from 7:00 am until 9:00 am, you can close a lane on a certain link between 8:00 am and 8:45 am (Figure 8). Traffic controls can change any link property or combination of link properties. The change can be done with a new absolute value for the property or on operation on the existing value, such as multiply the speed by 0.5.

A global network change is meant to implement conditions which affect the whole area, such as the drop of free speed and capacity of links due to bad weather conditions.

State of the background traffic

Background traffic is defined as the usual traffic on a working day. For each OD-pair the relationship with the threatened area is known: in-going, out-going, through-traffic or external-traffic (Figure 9). Each of these types of relationships with the threatened area can be scaled.

For a large evacuation the traffic system will be overloaded and this will lead to congestion. Efforts of the participants to reduce or eliminate this background traffic will be implemented by the response cell. This is done by reducing one or more of the four types of background traffic by a factor. For instance: prohibition and strict enforcement of in-going traffic will lead to scaling of in-going traffic with zero.

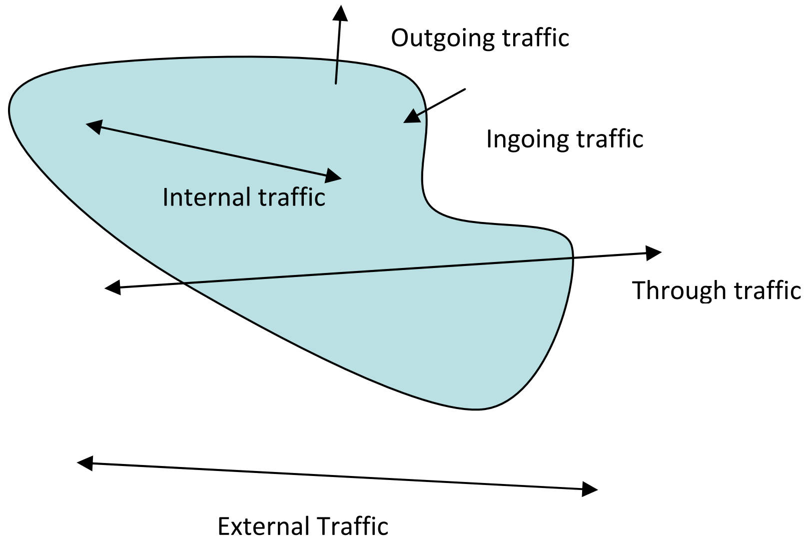

Figure 9 Definition of types of background traffic

Departure of evacuees

The departure rate of the evacuee is defined by a logistic curve (also known as S-curve). The characteristics of this curve can be changed with each time step (Figure 10). Depending on the actions of the participants, and in particular the information and instructions for the population, the response cell will set the characteristics of the departure rate.

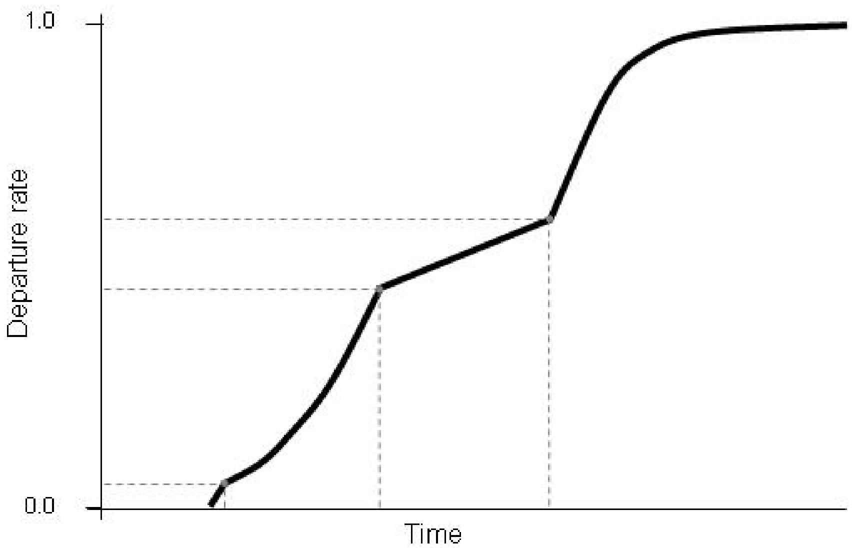

Figure 10 Principle of change of the departure rate during the evacuation

Destinations of evacuees

The response cell has three options in setting the use of the exits by the evacuees: (1) all exits are equally weighted; (2) the exits are weighted according to aim and efforts of the participants and (3) the exits are weighted by the capacity of the exits. The response cell will interpret the activities of the participants in regards to the destinations of the evacuees. An exit is closed for use by giving a weight of zero.

Calculation of the evacuee OD-matrix

Here the response cell has three ways to distribute the origins of the evacuee to the exits: (1) distance from the origin tot the exit has no importance; (2) the distance to the exit is of importance[3] and (3) the evacuee will go to the nearest exit.

With the second method, it is possible to define sets origins and destinations. Each set should have at least one exit and each origin should be part of one set. It is not necessary to include all exits.

For the last method, nearest exit, all exits are included with a weight larger than zero.

The choice of exit and the type of distribution result in seven combinations for building the OD-matrix for the evacuee.

Table 2 Combining distribution and choice of destination to the OD-matrix for evacuees

		Choice of destination			
		No explicit choice – all exits are equal weighted	Exits are weighted	Exits are weighted by capacity	Is determined by the distribution
Distribution	Distance has no importance	(1)	(2)	(3)	
	Distance to the exit is of importance	(4)	(5)	(6)	
	To the nearest exit				(7)

Macroscopic Dynamic Traffic Assignment

The OD-matrices of the background traffic and the evacuation traffic will be assigned using the macro dynamic traffic assignment of OmniTRANS. For all links in the network the traffic conditions (number of vehicles, speed and traffic flow) are available for analysis. The client server will regard people on flooded links as victims as well as those people who are still at home. The attributes speed and capacity of these links will be set to zero by the client server. Further travel for the vehicles on these links is not possible any more and people can't leave flooded houses.

[3] This is implemented by using a Gravity model.

Calculation of the travel times between zones

A request for a resource will lead to the assignment of a specific task for the resource on a specified location. In some cases the resource needs to come from another location. Travel to the location could be necessary. During the reallocation, the resource is not available. The time span that the resource is not available is equal to the travel time. The travel times are calculated with MaDAM. The client server will keep track of location and status of the resources.

7 Application of the instrument

As part of the development and testing of the application the instrument is applied in two training sessions [6, 10].

In December 2007, the municipalities of Maassluis, Vlaardingen and Schiedam as well as the safety region Rotterdam-Rijnmond and the water board Delfland held a joint training session for the strategic decision level.

For this first time application, the focus was on testing the robustness of the application and gathering experience in how to use the instrument in a training session.

All the components of the instrument (clients, client server and OmniTRANS server) were installed on one machine. The application worked as expected, without failures.

The main conclusion of this first test was that the goals of the training, setup of the session and nature the feedback should be known by the participants.

It was the first time that participants were confronted with misjudgements of the availability of resources. For example: several participants tried to claim the same resource; a participant expected a resource would be available but did not take in account that it was delayed due to traffic jams.

The actual traffic situation showed to be quite different than expected by some participants. The reasons for this were false assumptions about decisions of others and a lack of coordination.

In May 2008, the tool was applied by the safety region Utrecht for a specific group of decision makers, the regional operational team. The goals for this session were:

- Learning more about the dynamics of river flooding and preventive evacuation.
- Preparation of decisions and dilemmas for a higher decision level.
- Translation of tactical dilemmas to decisions for the operational level.
- Improving systematic and disciplined information gathering, deliberations and decision process.

The tool was used in a network configuration where several members of the response cell worked simultaneously on the preparation of runs and interpretation of the results (Figure 11). Many runs of one or more hours each were made. In total two days were simulated.

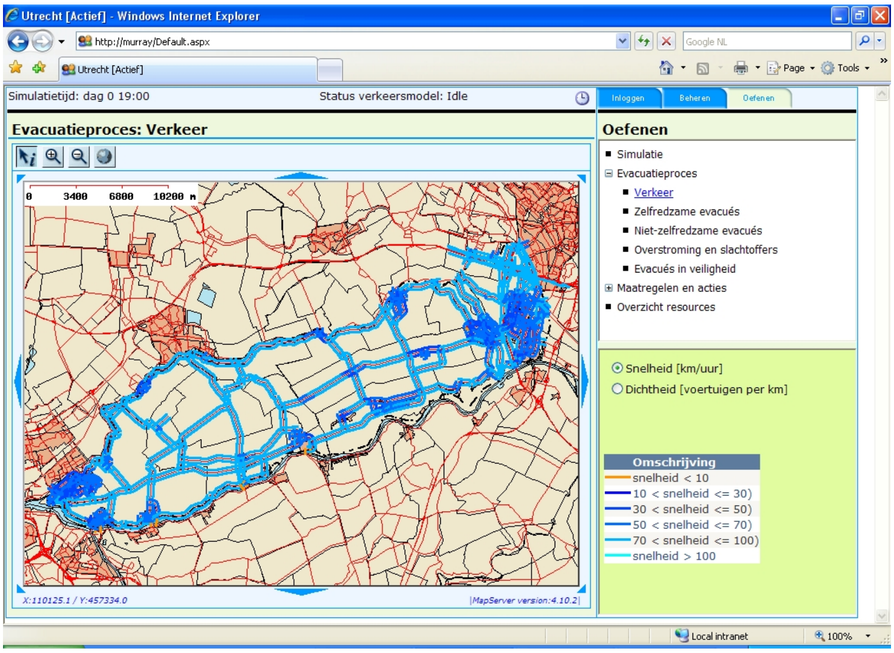

Figure 11 Example of output during the training session of the safety region Utrecht

The detailed and coherent feedback in the situation reports was appreciated by the participants.

At the end of the training session, during the evaluation, the output of the simulation was shown to the participants. They were very interested in maps, graphs and tables produced during the simulation.

In the training sessions the preparations of a model run (interpretation of the decisions of the participants to parameter stetting of the model stages) took ten to twenty minutes. The actual modal run took several minutes per hour in the virtual environment. Interpretation of the model results and the writing of the situation report took ten to fifteen minutes.

In relative simple stages of the training setting a full cycle could be in a range of twenty five to thirty minutes. In a more complex situation forty till forty five minutes is needed. Detailed specification of decisions can lead to longer response times. For instance: long lists of movement of special equipment and troops.

8 Concluding remarks

A support tool is developed to support the response cell in giving consistent and realistic feedback in training sessions where a large scale evacuation is inevitable. The developed tool integrates the progress of the threat, the state of the traffic system as well as the resource planning.

In the training setting the response cell is responsible for the interpretation of decisions of the participants. This will result in changes in the supply and/or demand side of the traffic system as well as the resource planning. The support tool will simulate the resulting state. The results are used for situation reports for the participants.

Application of the tool in training sessions showed that it can contribute to a meaningful and well appreciated training. The goals of the training, setup of the session and the nature of the feedback should be known by the participants.

Depending on the setup of the training, the size of the network and the level of details of the decision of the participants the response time of the response cell can be critical. In the two exercises the response time was forty minutes at most.

The tool gives the opportunity to add extra dimensions to training sessions. In multi disciplinary large scale operations the coordination of activities is critical. With this tool it is possible to include coordination tasks as:

- the use of scarce resources for those tasks where they contribute best
- measures to divert, reduce or even eliminate non-evacuation traffic on the evacuation routes.

It is possible to develop training setting where specific tasks of the response cell are fulfilled by some of the participants. This will require extra instruction. The client-server architecture is prepared for this. A user can be restricted to perform specific tasks.

The tool can be applied in a wide range of emergency situations, not only flooding. In the current setup of the tool the minimum time step is set to one hour. This could be to short for some emergency situations. For these types of situations a shorter time step could be used.

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