Evacuation a serious game for preparation

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Abstract— **Mass evacuation is a measure to reduce possible loss of life in the case of potential disasters. Planning for mass evacuation is only useful if these plans are tested and evaluated by government and the public in reality or in simulated events. As a result, any prior experience is likely to be outdated by the next incident, because social structures, public perceptions, perception of decision makers, emergency planning and infrastructure all change over time and based on the previous experience. Especially in the Netherlands mass evacuation in the case of large-scale flooding is once-in-a-lifetime experience or less event because of the high protection level for flooding. The use of serious gaming is an alternative to gather required experience of conduction an evacuation in several events. This article describes the development of a serious game for mass evacuation, as well as experiences gathered from exercises using SPOEL. Finally is concluded that it is possible to evaluate emergency planning for evacuation and develop realistic experience through exercises using SPOEL, in an effort to compensate the gap in experience because of a lack of real life mass-evacuation experience.**

I. Introduction

Evacuation is a possible measure to reduce loss of life and prevent damage of movable goods in case of a disaster or a threat of disaster [1]. Disasters worldwide show the possible result of evacuation. For example during for hurricanes and flooding people and movable goods might be saved. Also evacuation of building in case of a fire, (a threat for) a terrorist attack or nuclear or chemical accident or an earthquake can reduce loss of life because people are put out of dangers. Evacuation has the potential to save lives, but could be costly in time, money, and credibility [2].
Evacuation is defined as the movement of individuals to a (relatively) safe location. Different types of evacuation can be defined depending on the destination and opportunities for movement before or after the onset of a disaster [3, 4] (for example a dike breach or earthquake). Preventive evacuation refers to operations in which the process of movement to an area outside the exposed zone begins prior to the onset of a disaster. When time before a disaster is too limited for large-scale preventive evacuation, people can evacuate to shelters or evacuate vertical in their homes. Following the beginning of a disaster evacuation, rescue operations may be ongoing, in which individuals are evacuated from exposed areas by rescuers. Escape refers to the cases in which individuals are able to leave the exposed area on their own after the onset of the disaster. In the period between the start of the disaster and the beginning of significant exposure, acute evacuation may occur. A strategy for evacuation may combine some or all of these different types of evacuation.

The concept of a safe place is relative, since the possibility of loss of life depends heavily on local circumstances. People who shelter within an exposed area during a disaster may have a larger probability for loss of life than people who evacuate preventively, but less then people in their cars [5].

To prepare for a mass evacuation, organisations develop emergency planning protocols and planning documents for all kinds of disasters. For this research we considered a mass evacuation as characterised by one of the following elements:

- (Possible) congestion on available infrastructure that limits possibility for transportation in time.
- Shortage of rescue services and rescue equipment related to necessary capacities for control.
- Different involved stakeholders with equal responsibilities.
- When citizen's response could be a significant factor in the required time for an evacuation.

The logistic process of evacuation before being exposed is different from evacuation and rescue operations that occur after being exposed. After being exposed, the infrastructure might be impacted by the flood. Also the physical options of people might be impacted. The situation after a flood or a disaster will also change quickly over time in the hours after the onset of a disaster. People will help each other, with or without rescue services [6]. The available infrastructure after a flood is unknown, because the size of a future flood is as of yet unknown.

II. Scope of this Article

In this article, we focus on mass evacuation, the potential of serious gaming for evaluation, training and exercise planning activities for evacuation. In this article, we describe the model (serious game) for mass evacuation 'SPOEL', which can support the evaluation of flood preparedness in the absence of real experience. Also two case studies are described for the Netherlands in which this model was used. The lessons experiences are compared to lessons learned from real evacuations in the New Orleans (Louisiana) area. Finally, we address issues related to coordinating mass evacuations when multiple local or regional organisations with equal authority are involved related to serious gaming.

III. Flood Risk and Evacuation in The Netherlands

Recent national emergency planning for flooding is based on the philosophy that mass evacuation (in case of a threat of flooding from the sea or from rivers) should be a once-in-a-lifetime event [7]. In the case of the Netherlands, then, it seems nearly impossible to depend on the occurrence of frequent actual evacuation events for evaluation of the nation's readiness.

Research has shown that in order for Dutch authorities to maintain the capacity to implement a preventive evacuation (when people leave the threatened area before a possible dike breach) in the event of flooding, national crisis management and national traffic management are required because such an event is a national crisis [8-10]. Within a critical time window (between early warnings based on forecasts and the start of the disaster), it may not be possible to evacuate coastal areas in time, because of the number of inhabitants and the limited road capacity [11, 12], other destinations have to be used. The Dutch Parliament stated in 2006 [13] that: The Netherlands had to improve the preparedness of its organisations and of the public for possible flooding. In addition to prevention, more attention was needed for planning and exercises. Several regional and national emergency plans have been developed for flooding and evacuation [14].
As part of the program defined in 2006, a national exercise called 'Waterproef' was organised. This exercise mainly focused on the decision-making process using available systems and planning information. In case of evacuation, only the decision-making process was part of the exercise. The consequences of the decisions and the possible impact of these alternatives were not part of the exercise. This element was addressed as one of the main topics for further preparation, as were relations between the public and different national and regional organisations. The possible impact of combined measures, and the need for evaluation, training and exercise of evacuation activities in case of flooding are also addressed [15]. Helsloot and Scholtes call all existing planning purely focussed on the own organization and with no attention for the overall results "symbolism" [16]. Therefore more knowledge about these consequences is required.
In the Netherlands, we lack frequent experience with evacuation. The flood of 1953 resulted in an increase of safety levels, with the goal of preventing such a situation from ever occurring again. Moreover, the evacuation of 1995 due to extreme water levels in Dutch rivers also resulted in improvements the strength of flood defences.

IV. Effectiveness of Evacuation

Evaluation of evacuation aims to test whether the desired outcome can be achieved. In the case of mass evacuation, the outcome not only depends on the infrastructure, but also (largely) on the decision-making processes of all emergency organisations, and of the public as a whole. The necessary time for evacuation, assuming a certain set of decision-making processes, can be calculated using models such as the 'Evacuation Calculator' [17], National planning, monitoring and training Module for Evacuation, [18], and DSS Escape [19]. However, none of these models included decision-making processes with dynamic calculations, or presented the consequences in an exercise setting.

The impact of the decision making process on the outcome of an evacuation is shown by the Waterproef exercise in the Netherlands [14], and also in the United States, comparing differences between the evacuations following warnings for hurricanes Katrina and Gustav [20], and in particular, evaluating the evacuation efforts after Katrina [21, 22].

Evacuation, which combines the effects of decision-making, the consequences of taking specific measures, and the impact of available infrastructure, can be accomplished by:

- Evaluating real events; In the case of preparing for hurricanes in the United States, evacuation is a frequent event. The possibility for evacuation is a part of life, and both the public and decision makers often have some kind of experience that can be used. The evacuation (in preparation and response) to Hurricane Gustav used lessons learned by the government, industry, and the public following hurricanes Katrina, Rita and Ivan [21, 23, 24].
- Simulations using models that combine decision-making processes likely to be employed by the public and by government, the use of available infrastructure and information regarding the possible threat.
  This article describes such a model, and the results from using the model are shown in Fig. 1.
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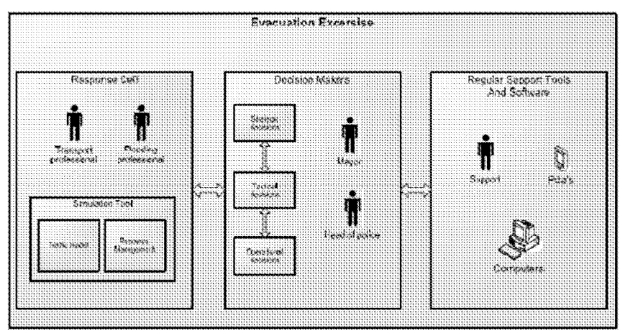

Fig. 1. Scheme for disaster simulation using models that combine the decision-making processes by public and by government with the use of available infrastructure, as well as information regarding the possible threat [25].

V. Description of the Evacuation Exercise Instrument 'SPOEL'

The evacuation exercise instrument 'SPOEL' is a simulation model developed to (on individual basis but also for teams en combination of teams) train, prepare, and evaluate individual players and multi-participant response systems for a mass evacuation. The instrument can be seen as a simulation game for emergency response professionals. The model was developed as part of the program Living with Water in the project 'From threat to evacuation - learning to evacuate' [25].

SPOEL simulates the evacuation process prior to exposure to the consequences of a disaster (in this case a flood). The start of the exercise (T-0), the disaster (T-D) and the development of the disaster and its aftermath are defined by the user [26]. An evacuation can be initiated during the exercise following detection of a possible threat and its effective interpretation by decision makers.

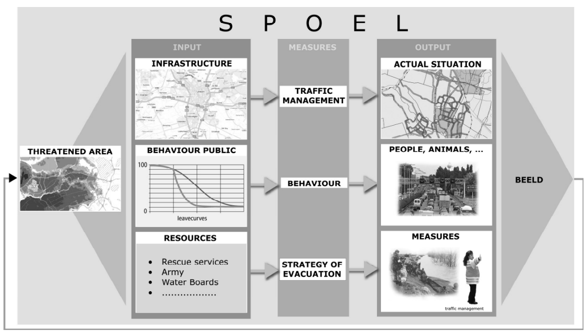

Fig. 2 SPOEL.

Before the simulation, the user defines the area that will participate in the exercise, training or test. By changing parameters at the borders of this area, the simulation area can be varied. In the case of vertical evacuation, shelters can be defined as destination inside the threatened area. Also, public shelters outside the threatened area can be defined as evacuation destinations. For example, simulations may only focus on the area to be evacuated, but may also include logistical processes outside the evacuation zone as part of the exercise. At the start of the exercise, all involved stakeholders that take part must be defined. Stakeholders are associated with their own resources.

SPOEL combines:

- Several threat scenarios
- Public behaviour
- Resource Management
- Traffic Management and road networks
- Special objects

Multiple threat scenarios
Before an exercise, training or test, a user can define the threat and the development of the disaster in time. The user must define the start of the disaster (T-D) and the affected area, which could increase in time (T-D+1, T-D+2 etc). The period between T-0 and T-D is the span of time available for preventive evacuation.

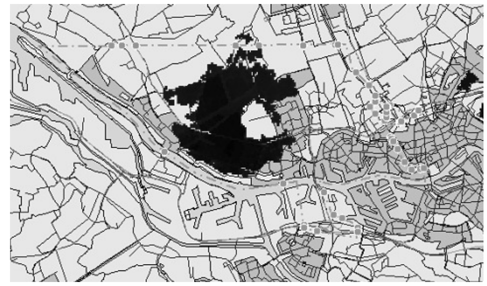

Fig. 3 Flooding scenario in SPOEL at certain time step.

Public behaviour
At T-0, the user defines the number of people inside each zone and the different classes of self-supporting or non-self supporting populations. Also, other groups to be evacuated, such as animals, can be added to the simulation. For non-self supporting populations, a pick up location can be defined in each zone. Also, the default behaviour(s) of the public, which may change over time, is defined in the model (departure time curve, route choice and destination, % of people who do not evacuate, etc.) during the period of simulation. The default behaviour can be based on the response and specific role of the media, and development of the threat and its perception by the public will be part of the scenario.

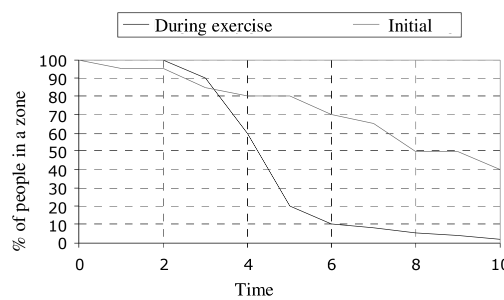

Fig. 4 Change of initial behaviour after decision making.

During the simulation, initial public behaviour may be changed (Fig. 4) by decisions made by stakeholders as part of the simulation (for example, crisis communication). Possible measures can be translated into expected public behaviour (by experts) and added to the simulation in order to change the default public behaviour. In addition to incorporating different public behavioural responses, the model also accounts for the limited capacity of roads during the evacuation. Specifically, once roads reach a certain capacity, the departure of additional individuals by road is not possible and will be delayed.

Resource Management
The location and inventory of resources (both equipment and personal) available to each stakeholder must be specified at the beginning of the exercise. In order to model the possibility of a call by responding agencies for outside assistance, other

stakeholders outside the simulation area (corresponding to assistance from other regions or national organisations) can also be simulated, and can deliver additional rescue equipment. During the simulation, preventative and response measures can be implemented only when the requisite resources are available. The user must define the period (hours) required to implement each measure, after which the allocated resources can become available again for additional measures. Measures can also be aborted.

The model also accounts for transportation requirements and travel time. At the moment that a response measure is initiated, the necessary travel time is calculated using the actual status of road networks at that moment. It is possible to reduce the travel time of responders by a given percentage if responding vehicles are escorted by emergency vehicles with sirens and/or flashing lights.

Traffic Management and road network

At the start of the exercise, available roads and exit points can be defined and road capacities can be varied. During the simulation, measures can be taken to influence the road network (when resources are available).

SPOEL can take into account the influence of internal and background traffic, incoming traffic, and traffic passing through the area, as well as traffic leaving the area.

Several possible strategies have been pre-defined for traffic management in SPOEL, which can be modified by users during the exercise:

- All exit points are equally attractive, and no regulations are imposed for route selection (default).
- The user defines the attractiveness of each exit point, no regulations for routes.
- The attractiveness of each exit point is related to its capacity, no regulations for routes.
- The nearest exit is the most attractive, routes will be selected based on the shortest distance.
- All exit points are equally attractive, routes are based on minimal travel time.
- The user defines the attractiveness of each exit point, routes are based on minimal travel time.
- The attractiveness of each exit point is related to its capacity, routes are based on minimal travel time.
- Strategy is fully determined by the user, by connecting each zone to a corresponding exit point; routes are based on minimal travel time.

Also, flow in the opposite direction (also called reverse laning, contra flow) can be added as part of the traffic management simulation. All measures that influence the road network must be translated by the user into 1) the capacity of a road, 2) the maximum speed of vehicles and 3) the maximum speed of vehicles when the road is at full capacity. Blocking of roads is possible, reducing the capacity of blocked roads to zero. The influence of weather can also be taken into account by adding a weather factor to the total network.

Special objects

Special objects, which may depend on or be initiated by a logistical process, can be added to the model by defining the location and the responsible stakeholder (including equipment) for each object. Consequences of the failure of special objects are translated into effects on the participants of the exercise as a response factor leading to a greater or lower degree of control over the exercise.

Presentation of results

During the simulation, each user can take measures and make decisions for each time step. The consequences of each measure are presented to each stakeholder in terms of:

- Availability and use of own resources (tables)
- Actual density and speed on road network (map, Fig. 7)
- Status of the evacuation (graphs and tables):
    - Evacuated people for each zone (and number of people still to evacuate, divided into self-supporting and non-self supporting)
    - Evacuated people for each object (and number of people still to evacuate [e.g., for a hospital])
    - Actual departure curve for each zone
    - Total number of evacuees:
        - Who evacuated successful (reached destination)
        - Who did not start evacuation yet (are still at home)
        - Who are still evacuating
        - Who failed to evacuate (those who are exposed to the disaster)

The status of the evacuation can be translated to the exercise by higher and lower degrees of control. Another option is to use participants of the exercise who can use status reports from SPOEL to make reports and recommendations for their own organisation based on the development of the scenario and possibility of the infrastructure.

The results are presented for every hour. After each hour, new measures can be implemented by all users before the next step. The calculation time depends on the size of the exercise. For one average dike-ring the calculation time is less then one minute.

About the instrument

The instrument is as web-based application with a GIS interface. The structure is showed in Fig. 5. SPOEL uses a road network model as a separate module (the dynamic macroscopic traffic model of OmniTRANS International, MaDAM [27]). All participants in the exercise are able to log in (using their own account) to the instrument and implement their decisions. The availability of their own resources and actual travel time are used as boundaries for each user. The technical description of the instrument is reported in [28].

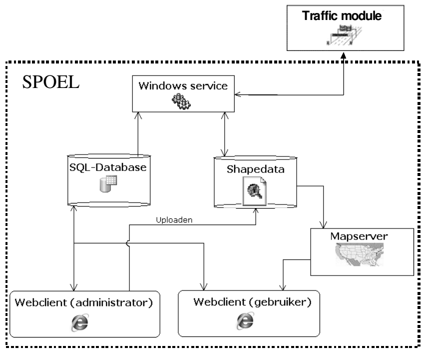

Fig. 5 Modules of SPOEL.

One of the default stakeholders is higher and lower control. During an exercise they can introduce events and add elements to the scenario as external players of exercise control.

VI. Case study: Use of SPOEL in exercises in the Netherlands

SPOEL has been used in two exercises during the development of the instrument [25]:

- Safety region Rotterdam-Rijnmond: SPOEL was used to support higher and lower control to deliver feedback to participants (operational and strategic level) of an exercise including the safety region of Rotterdam Rijnmond, the Water board of Delfland and the cities of Schiedam, Vlaardingen and Maassluis. A scenario was developed for a sudden dike breach that caused flooding in one of the involved cities (which also became the area of the evacuation exercise).
- Safety region Utrecht: SPOEL was used to give direct feedback to all participants of a multi-disciplinary regional operation team (including fire brigade, police, medical services, water board, municipalities, etc.) for several scenarios involving (possible) flooding of the river 'Lek'. The area of the exercise was 'Dike-ring 15'.

Before each exercise, SPOEL was configured and implemented with local information. Zip codes were used to designate most zones. The Dutch 'New Regional Model' [29] (Fig. 6) was used as the traffic model, and included socio-economic data for each zip code and for the network. Also, the local information of rescue services (location, equipment, personal) and the information of special objects were included in the simulations. This information was delivered by each safety region.

Fig. 6 Base of network [29].

The use of SPOEL allowed the consequences of strategic decisions to be used to generate direct feedback for decision makers. Also, the translation of strategic decisions into operational measures, the consequences of these measures and real-time communications could all be simulated using realistic models. The use of the instrument in the exercise resulted in the delivery of realistic feedback to the participants, and gave insight in their actions.

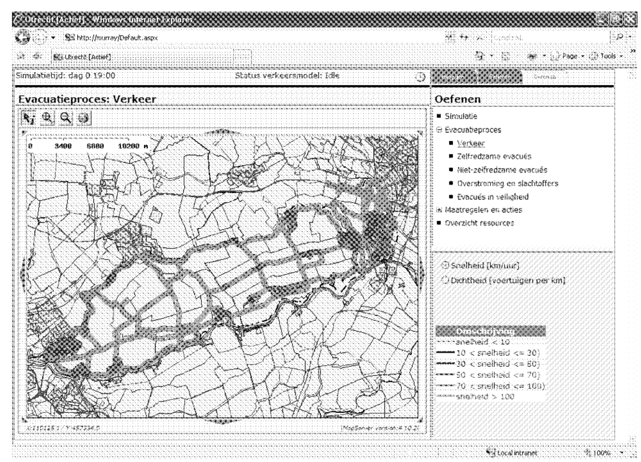

Fig. 7 Output showing actual traffic speeds during an exercise in safety region Utrecht (Screen shot of SPOEL, text in in Dutch)

An evaluation of the use of the SPOEL instrument highlighted the importance of proper implementation and education. The model's use and display of the realistic consequences of decisions and measures, as well as the delivery of direct feedback during each mass evacuation exercise creates a new and valuable user experience. Because emergency agencies and disaster response stakeholders often lack direct experience with flooding and other disasters for which response time may be critical, knowledge and experience must be developed and maintained at all levels.

VII. Conclusion

Evacuation procedures and decision-making processes must be rehearsed and evaluated in the context of ever-evolving social and institutional landscapes and physical infrastructure.

When responders lack firsthand experience orchestrating large-scale evacuations, simulations can be used to prepare government and institutional stakeholders and decision-makers. The evacuation exercise instrument 'SPOEL' is a model that can be used to evaluate the consequences of decisions and response measures during a simulated mass evacuation.

Although real events may create bottle necks that are not part of the model (as described by Wolshon [21] in the case of New Orleans), simulation of mass evacuation is nonetheless a valuable tool for The Netherlands to achieve a minimum level of experience among personnel in its rescue services. By varying different exercise scenarios, rescue services can create a resilient organisation that can anticipate and effectively respond to a variety of different situations.

Evaluating and simulating large-scale strategies of evacuations through exercises is a new technique, but a necessary first step towards the highest possible level of planning and emergency preparedness for flooding and other potential disasters.

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