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BLOCKING ROADS TO RAISE THE EFFICIENCY OF AN EVACUATION

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ABSTRACT

In this paper, the effectiveness of different approaches to raise the efficiency of an evacuation is compared. The approaches are based on the optimized traffic assignment and compared with an uncontrolled evacuation. The first approach is a well-known approach, namely to give instructions to the evacuees. The other approaches are to block the roads that are unused in the optimal traffic assignment and the combination of blocking roads and giving instructions. For all approaches, the resulting demand and route flow proportions follow from the optimized assignment and the preferences of the evacuees. Although the blocking of roads does most probably not sound like an effective approach, it can help to increase the outflow of the network and thus the evacuation efficiency. In a case study is showed that the effects of the approaches are case specific: they are effective in some situations, but have a negative influence in others. Thus, depending on the specific case, the authority can choose one of the approaches to implement an optimized assignment, based on the performance of the approaches for the specific case and the available means.

KEYWORDS

Evacuation, Traffic Assignment, Implementation, Instructions, Blocking roads

INTRODUCTION

Natural disasters, like bush fires and floods, often cause many casualties. To avoid this as much as possible, authorities have to be prepared for such disasters. This preparation includes creating a plan to evacuate people from a threatened region. Departure times, destinations, and routes have to be assigned to the traffic leading to an efficient or even optimal evacuation from a systems perspective. Several parts of the traffic assignment can be optimized, see Miller-Hooks & Sorrel (2008) and Stepanov & Smith (2009) for examples of the optimization of route assignment, Saadatseresht et al. (2009) for an example of the optimization of destination assignment, and Sbayti & Mahmassani (2006) and Afshar & Haghani (2008) for examples of the combined optimization of departure time, destination and route assignment. Besides optimizing the assignment it selves, it is also possible to optimize the network for which the assignment is optimized, for example by optimizing link or lane reversal (see for example Tuydes & Ziliaskopoulos (2006), Kim et al. (2008), and Xie et al. (2010)).

An important question is how such an optimized (or even optimal) traffic assignment has to be implemented. Without any interventions, the decisions that people make are most likely not equal to the optimized traffic assignment. The reasons for this are that people act out of a user optimal thinking, while the traffic assignment is optimized for the system, and a lack of information about and experience with the extreme situation. Thus, the people have to be encouraged or even forced to act like the optimized traffic assignment, to approach this assignment as close as possible. In all studies mentioned in the previous paragraph, attention for the implementation of the optimized assignment is limited (the optimized assignment is mostly considered as a bound on the system performance).

In this paper, the effective implementation of the optimized traffic assignment is investigated by comparing the effectiveness of different approaches. First, the optimized assignment is implemented by instructing the evacuees to follow the assignment, whereby the people can partly comply with the instructions (full compliance would equal the optimized assignment but is behaviorally unrealistic). In this case, the traffic flows follow from the optimized assignment, the compliance level and the assignment preferred by the evacuees. The effect of instructions in combination with compliance levels is earlier investigated in Huibregtse et al. (2009) and Pel et al. (2009). For most optimized traffic assignments hold that only part of the network is used in the optimized assignment instead of the whole network. The second approach is based on this: the assignment is implemented by blocking the roads that are unused in the optimized assignment. Here, the resulting assignment is the assignment preferred by the evacuees based on the reduced network. The third approach is the combination of the previous approaches: evacuees are instructed to follow the optimized assignment, whereby they can partly comply, and roads are blocked which are unused in the optimized assignment. The approaches can be applied independent on how the optimized assignment is obtained.

First of all, the approaches to implement the resulting optimized assignment are discussed. Then, the effectiveness of the approaches is compared in a case study.

THE IMPLEMENTATION OF THE OPTIMIZED TRAFFIC ASSIGNMENT

In this section, the three approaches to implement the optimized assignment introduced in Section are explained: 1) giving instructions to the evacuees, 2) blocking the roads that are unused in the optimized assignment, and 3) the combination of instructions and blocking roads. For these approaches holds that the resulting traffic flows follow from the optimized assignment and the preferences of the evacuees.

Approach 1: Evacuation instructions

The first approach is to instruct the evacuees to follow the optimized assignment. The assignment is optimal from a system perspective, and is most probably not similar to the optimized assignment from the perspective of the evacuees. The demand and route flows follow from instructions, a compliance level and preferences of the evacuees and are determined by two models, both part of the evacuation traffic simulation model EVAQ and described in Pel et al. (2008). The models are shortly described in this section, for more information see the reference.

In the first model, the evacuation demand is computed. The idea is that each resident continuously has the opportunity to either evacuate or decide to postpone the decision to evacuate. The probability to evacuate multiplied with the population gives the demand for each origin. This probability to evacuate is determined for each time period by a binary logit model and depends on the following factors: 1) the difference between the current time period and the time period the hazard strikes the origin and 2) the difference between the current time period and the instructed departure time.

The route flow proportions are determined by the second model. This model is a multinomial logit model containing the following factors 1) the instantaneous travel time on the routes, 2) the overlap between the destination and the instructed destination, 3) the overlap between the route and the instructed route and 4) the overlap between the links in all routes. In the application in this paper, all possible routes on the network are considered in determining the route flow proportions.

Both models contain a compliance parameter. The value for this parameter can be varied from 0 up to and including 1. If the value is equal to 0, the instructed assignment has no influence. In this case, the only factor determining the demand is the difference between the current time period and the time period the hazard strikes the origin and the only factor determining the route flow proportions is the instantaneous travel time on the routes. If the value is equal to 1, the evacuees will follow exactly the instructed assignment, independent on the other factors. Increasing values between 0 and 1 have a non-linear increasing effect on the probability to evacuate.

Approach 2: Blocking roads

The second approach is to block the roads that are unused in the optimized assignment. By blocking roads, the summed capacity over all links on the network is decreased. Therefore, blocking roads does most probably not sound like an effective approach. But, the expectation is that blocking roads can be effective because the evacuees are forced to follow links that are included in the optimized assignment. Therefore, blocking roads could lead to an increase in the outflow of the network and thus an increase in the evacuation efficiency.

The links that are blocked are the links that are unused in the optimized assignment. These links are blocked for the whole evacuation duration. Thus, the blocking of roads leads to a new network. In this approach, evacuees make their own departure time, destination, and route decisions, whereby the optimized assignment is only indirectly taken into account via the adapted network. The changed network leads to a changed set of all possible routes. The demand and route flow proportions are determined in the same way as described in the previous section, with the compliance parameter equal to 0. Thus, the only factor determining the demand is the difference between the current time period and the time period the hazard strikes the origin and the only factor determining the route flow proportions is the instantaneous travel time on the routes.

Approach 3: Combination of evacuation instructions and blocking roads

The third approach is to combine evacuation instructions and blocking roads. Thus, the effectiveness of evacuation instructions is determined for the situation with blocked roads. The demand and the route flow proportions are determined by the earlier mentioned models, with the difference that a new network is created without the blocked roads causing another set of all possible routes.

CASE STUDY

In a case study, the performance of the approaches is discussed, both compared to each other and compared to a situation without control and the situation of the theoretical optimized assignment.

Network and hazard

The optimization method is applied for two different cases. Both cases are hypothetical floods of Walcheren (see Figure 1), a peninsula in the southwest of The Netherlands. Over 120,000 residents from an area of 216 squared kilometers have to be evacuated, whereby the number of evacuees per vehicle is assumed to be equal to 2.5. Walcheren is flooded in four hours. The evacuation is assumed to start two hours before the flood, by which the time available to evacuate is equal to six hours. The difference between the two cases is in the spatiotemporal pattern; Figure 1 shows for both cases, Case Northwest and Case South, which part of the network is flooded after 2, 3, 4, 5, and 6 hours.

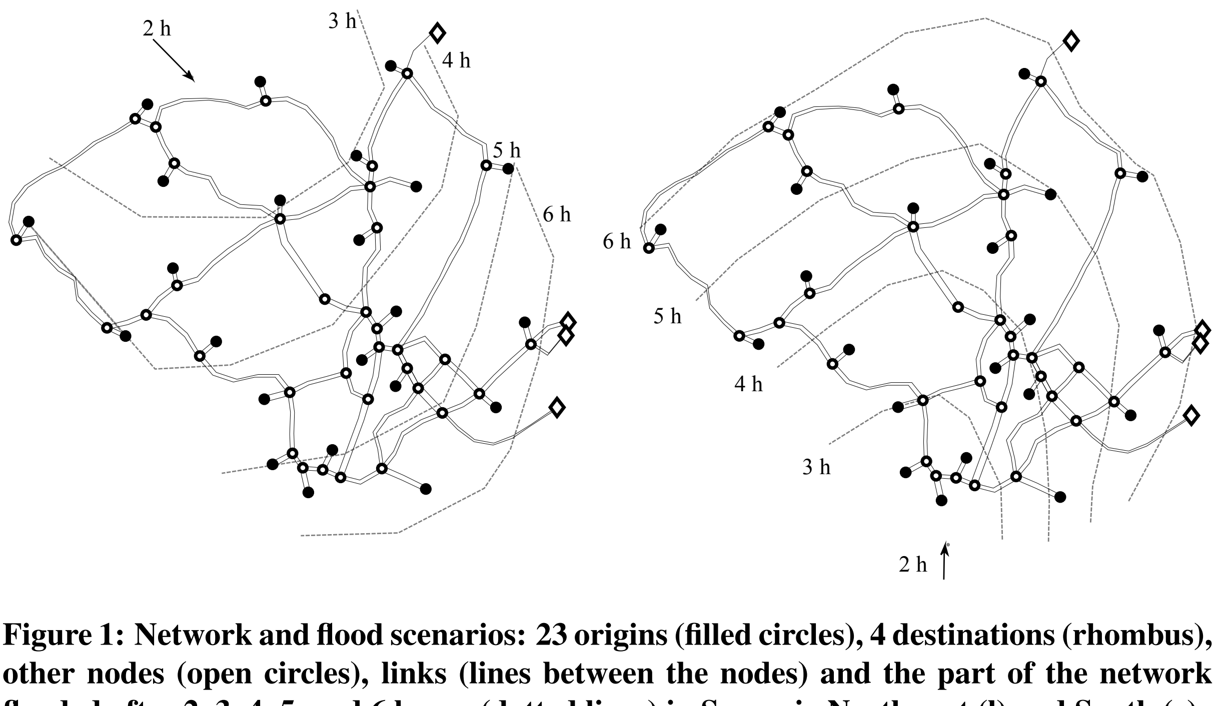

Figure 1: Network and flood scenarios: 23 origins (filled circles), 4 destinations (rhombus), other nodes (open circles), links (lines between the nodes) and the part of the network flooded after 2, 3, 4, 5, and 6 hours (dotted lines) in Scenario Northwest (l) and South (r)

Method to optimize the traffic assignment

As mentioned before, the approaches can be applied independent on how the optimized assignment is obtained. The optimization method used for this case study is the method presented by Huibregtse et al. (2009). This method leads to a departure time, destination, and route assignment for people in a region threatened by a hazard, and the performance of this assignment approaches the optimal performance. The optimization approach is based on ant colony optimization (see Dorigo et al. (1996)). In the approach (see Figure 2, assignments are created and the traffic flows as consequence of these assignments are simulated by an evacuation traffic simulation model. By using an objective function, the traffic flows are translated in a performance value, and this value is input for the next iteration of the optimization approach. More information about the optimization method can be found in Huibregtse et al. (2009).

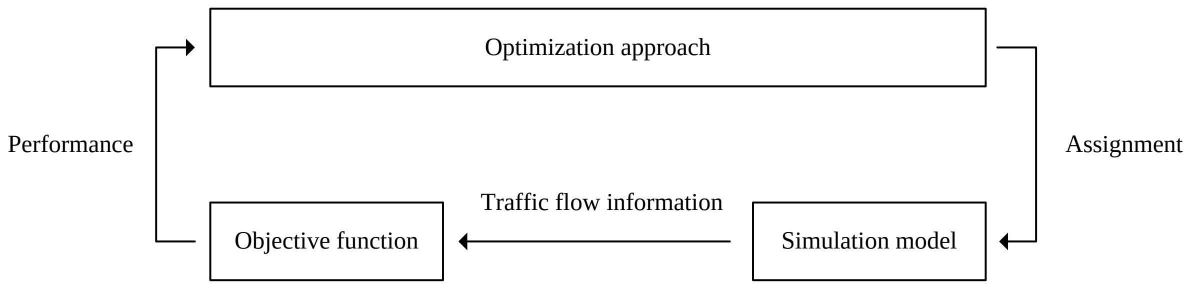

Figure 2: Simulation optimization approach

The evacuation simulation model used in this case study is the model EVAQ (more details can be found in Pel et al. (2008)). This model can be used to determine the demand and route flow proportions, and contains dynamic network loading with queuing and spill-back (propagation of the traffic flows through the network). The network degeneration caused by a hazard is included in the model.

The performance of the traffic assignment, f_E, is determined based on the arrivals over time by the following objective function:

$$f_E = \sum_{t=1}^{T} \exp(-\beta t) q_E(t) \tag{1}$$

where $q_E(t)$ is the number of evacuees reaching a safe destination in time period t, depending on assignment E, T is the time period with the latest arrivals and β is a weighting parameter with $\beta \geq 0$. This parameter makes the function generic: when $\beta = 0$ the optimization objective is equal to maximizing the number of arrived evacuees. When the value of β is higher, the importance of early arrivals is increased.

In this paper, the assignment is optimized under full compliance conditions. Thus, the evacuees will exactly follow the instructed assignment (the value of the compliance parameter is equal to 1).

Application

To be able to compare the effectiveness of the approaches to each other and to a situation without control and the situation of the theoretical optimized assignment, the performance of the situations listed in Table 1 has to be tested.

Table 1: Tested situations and their dependency on the optimized assignment and/or the evacuees' preferences

Situation	*Optimized assignment*	*Evacuees' preferences*
Theoretical: optimized assignment	$\surd$	
No control		$\surd$
Approach 1: Instructions (compliance level varied from 0.1 to 0.9)	$\surd$	$\surd$
Approach 2: Blocking roads	$\surd$	$\surd$
Approach 3: Instructions (compliance level varied from 0.1 to 0.9) + blocking roads	$\surd$	$\surd$

The optimization method explained in Section 3 is applied, resulting in an optimized traffic assignment. For the objective function, the importance of early arrivals is assumed to be of such a level that a suitable value for the parameter for the objective function, β, is 0.1. This means that evacuees arriving at their destination after 6 hours of evacuation have a weight of 55% compared to 100% for evacuees arriving at their destination at the start of the evacuation. EVAQ is used to test the situation without control, thus a compliance level of 0.

This optimized assignment is translated into departure time, route, and destination instructions and their effectiveness is evaluated whereby the compliance parameter is varied from low compliance (0.1) to high compliance (0.9), resulting in performance values. Also the second approach is applied, whereby roads are blocked based on the optimized traffic assignment leading to an adapted network. The third approach, the combination of instructions and blocked roads, is also tested for compliance levels varying from 0.1 to 0.9.

Results and discussion

Testing the situations listed in Table 1 is the same as testing the influence of instructions whereby the compliance is varied between 0 and 1 (compliance level equal to 0 means no control, from 0.1 to 0.9 is Approach 1 and equal to 1 is the theoretical optimized assignment) and testing the influence of instructions combined with blocked roads whereby the compliance is varied between 0 and 1 (compliance level equal to 0 is Approach 2, from 0.1 to 0.9 is Approach 3 and equal to 1 is the theoretical optimized assignment). Figure 3 shows the results of these simulations for respectively Case Northwest and Case South. The performance of all approached is lower than the performance of the optimized assignment, as has to be the case for an optimal assignment. Table 2 shows the improvement in the performance by blocking roads compared to the same situation without blocking roads. The performance of all approaches is discussed.

The effect of evacuation instructions (Approach 1) is to a large extent as expected: an upward trend is visible in the performance for an increasing compliance level for both cases. Remember that the effect of the compliance level on the demand and route flow proportions is nonlinear, thus based on these figures nothing can be concluded about the kind of upward trend.

The blocking of roads (Approach 2) leads to an increase in the performance for Case South equal to 6.7% and to a decrease in the performance for Case Northwest equal to 0.4%. While the improvement for Case South is relatively large, the approach will not lead to an improvement for all cases.

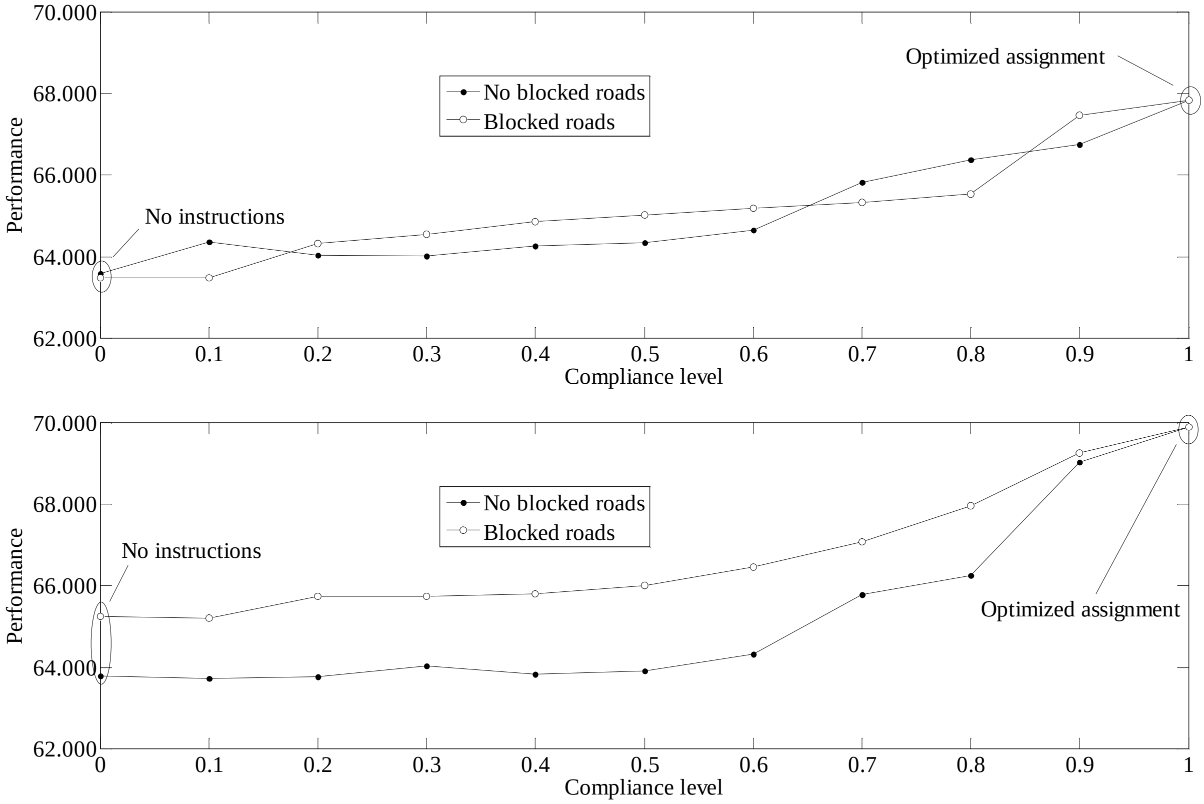

Figure 3: Simulation Results Case Northwest (top) and Case South (below)

Table 2: Relative improvement in the performance by blocking roads for different compliance levels for Case Northwest and Case South

Compliance level	*Improvement Case Northwest*	*Improvement Case South*
0 (no compliance)	-0.4%	6.7%
0.1	-3.4%	6.8%
0.2	1.1%	9.1%
0.3	2.0%	7.8%
0.4	2.3%	9.1%
0.5	2.6%	9.5%
0.6	2.0%	9.5%
0.7	-1.7%	5.4%
0.8	-3.0%	7.1%
0.9	2.5%	0.8%
1 (full compliance)	0.0%	0.0%

The combination of instructions and blocked roads is effective for some of the situations, while for others applying instructions without blocking roads is more effective. For Case Northwest the improvement in performance varies between -3.4% and 2.6%, for Scenario South between 0.8% and 9.5%. Thus, the effectiveness of the combined approach seems to be case- and compliance level- specific. An explanation for the positive effect of adding the blocked roads approach to a situation wherein evacuees can partly comply with the instructions is that the evacuees are more encouraged to follow the links corresponding to the theoretical optimized assignment. On the other hand, the assignment is optimized for full compliance and assignments optimized for other compliance levels will most probably be different. Thus, it can also happen that forcing the evacuees to follow the assignment optimized for full compliance leads to a lower performance.

CONCLUSIONS

In this paper three approaches are compared to encourage the people to make their decisions according to an optimized traffic assignment: instructions, blocking roads and a combination of these. In case of instructions, evacuees partly comply with the instructed assignment and partly follow their own preferences. By blocking the roads that are unused in the optimized assignment, evacuees are forced to use only the links included in the optimized assignment.

The case study shows that all approaches can be effective. If an approach is effective depends on the case and eventually the compliance level. The performance (the time-weighted arrivals) of blocking roads compared to the situation without control increased with respectively -0.4% and 6.7% for the different cases. The increase in performance of the combined approach of instructions and blocked roads compared to instructions approach is between -3.4% and 2.6% for the first case and between -0.8% and 9.5% for the second case (the range is caused by different values for different compliance levels). Thus, both blocking roads and blocking roads in combination with instructions can be effective but this does not hold for all situations. Now there are no signs for what situations the approach is effective, future research might lead to patterns in the results.

The authority can choose one of the approaches to implement the optimized assignment based on the performance of each approach for their specific case and the available means.

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