ALGORITHM FOR DESIGNING ROBUST ROAD NETWORKS

Combining the best of two worlds: modelling and expert knowledge

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ABSTRACT

There is a growing awareness that road networks, especially in major urban areas, are becoming more and more vulnerable to unforeseen disturbances like incidents because of the fact that the level of congestion keeps growing. Therefore, robustness measures have to be taken. In this paper the robust road network design problem is presented as well as a solution algorithm for solving the problem. The solution algorithm combines expert knowledge with advanced modeling techniques. In this way the method can be applied to large scale networks. This paper shows the quality of the algorithm for a test network.

KEYWORDS

Robustness, road network design, optimization algorithm, spare capacity, expert knowledge

INTRODUCTION

There is a growing awareness that road networks, especially in major urban areas, are becoming more and more vulnerable to unforeseen disturbances like incidents because of the fact that the level of congestion keeps growing. Furthermore, it becomes more difficult to recover from unforeseen disturbances since the spare capacity in the network reduces both in place and in time. The opportunity costs of vulnerability in the Netherlands can for example increase easily to more than 4000 million euro per year in 2030 (Snelder et al., 2008). This raises the question which measures can be taken to reduce the vulnerability or to increase the

robustness of the road network and where and when these measures should be applied. These questions refer to the robust road network design problem. The robust road network design problem is a complex problem. This paper contributes to the existing literature about robustness and network design by:
- presenting a method that combines expert knowledge of stakeholders with advanced modeling techniques both for evaluation and optimization which can be applied on large networks;
- combining a trip distribution model with a dynamic traffic assignment and a marginal incident computation model (Corthout, 2009);
- focusing on short term robustness against incidents;

In this paper first robustness is defined and some measures are presented which can improve the robustness of a road network. Thereafter the robust road network design problem is formulated as well as a solution algorithm for solving this problem. The algorithm is illustrated using a test network with 5 links.

ROBUSTNESS

Robustness is the extent to which, under pre-specified circumstances, a network is able to maintain the function for which it was originally designed. Vulnerability is the opposite of robustness. A network that is vulnerable is not robust, and vice versa. In this paper we focus on four different incident types (1: a car breakdown; 2: incident with 1 lane blocked; 3: incident with multiple lanes blocked and 4: rubbernecking). The extra travel time that is caused by incidents is used as an indicator for robustness.

Different measures can be taken to make the network robust against disturbances. This paper focuses on adding spare capacity to the network, on creating or improving route alternatives, on unbundling traffic flows and on adding buffers.

PROBLEM FORMULATION

The robust road network design problem is presented as a bi-level problem. On the first level the actual network design is made by minimizing the costs of vulnerability, travel times and capacity expansion costs. The network design depends on the flow which is determined in the second level by means of a stochastic dynamic traffic assignment. This assignment does not only depend on the capacities (and road type and speeds) that are determined in the first level, but also on the demand. The demand depends on the travel times which are an outcome of the dynamic assignment and therewith also depends on the first level in which the capacities (and road type and speeds) are determined.

SOLUTION ALGORITHM

In this section the design method is presented which consists of three steps and combines expert knowledge of stakeholders with advanced modeling techniques. Each step of the method is briefly explained below.

Step 1: Design standards. Designing a road network starts with specifying the design standards. The objective of designing/improving the network, the design variables and the restrictions are specified.

Step 2: Functional analysis. A functional analysis is an analysis in which the network performance of the basis network is evaluated. The basis network is the network that is used as a starting point for the network design. It could be the current network, but it could for instance also be the planned network for a future year. A macroscopic dynamic traffic assignment model combined with a marginal incident computation model is used to evaluate the robustness of the network. This evaluation method makes it possible to evaluate hundreds of incidents on large networks in less than one hour of computation time.

Step 3: Design process. In this step the robust road network is designed. The design standards and the results of the functional analysis are used as a starting point. A model can be used to get an idea on which location adding capacity is the most useful. At first the 'optimal' number of extra lanes for the regular situation is computed with a heuristic. Thereafter, the 'optimal' number of extra lanes of spare capacity for improving the robustness is computed with a genetic algorithm. After this modeling exercise experts have the opportunity to adjust the suggested network. They can indicate which alternative routes should be used and where and which amount of capacity should be added. Furthermore, they can add all kinds of other measures that improve the robustness of the road network.

After adjusting the network, the performance of the network needs to be evaluated again. The quality of the robust design is tested with the same model as is used in the functional analysis. Furthermore, this evaluation indicates what the remaining problems in the network are. A choice could be made to go back to the first design steps and change the network design slightly to eliminate or reduce these problems. This makes designing an iterative process.

Furthermore, there are several other feedback loops in the method, which are included to achieve equilibrium between demand, travel times/costs and network design. The setup of the architecture is such that all building blocks (trip distribution model, dynamic traffic assignment model, marginal incident computation model and two optimization models) can independently be used of each other and the number of times that each building block is called can also be specified by the user. In fact, some building blocks can even be left out (for instance the trip distribution model), which of course does imply that the user (or group of experts) has to make some basic assumptions on the outcomes of these skipped building blocks.

RESULTS

The functioning of the solution algorithm is illustrated on the test network that is presented in Figure 1. In this network link 1 and 2 have 4 lanes and link 3 has 3 lanes. Links 4 and 5 have 2 lanes. The demand exceeds the capacity of 3 lanes and therefore link 3 is a bottleneck.

The optimization starts with an initial dynamic traffic assignment and a run of the distribution model. Both models are iteratively run until convergence is reached. Thereafter, the network is optimized for regular circumstances. This implies that incidents are not considered at this stage. The optimization algorithm finds the following optimal solution: link 1 and 2 get 2 extra lanes, link 3 gets 3 extra lanes and link 4 and 5 get 1 extra lane. This implies that the bottleneck is removed. As a result of the improved travel times the demand for car trips increased with 35%.
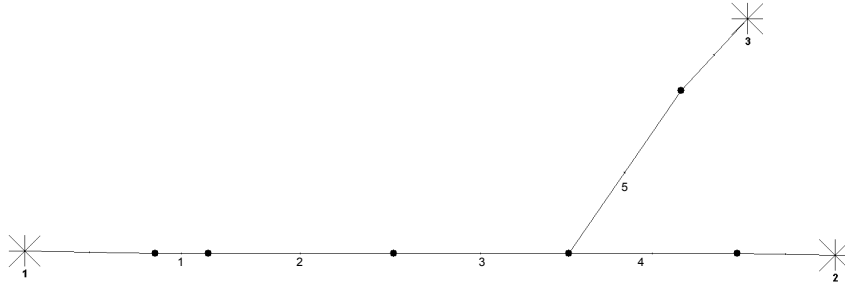
Figure 1: Test network

After the optimization of the network for regular conditions the network is optimized for irregular conditions (incidents). The genetic algorithm finds an optimal extra spare capacity of 1 lane for links 1, 2 and 3. This implies that in total links 1 and 2 get 3 extra lanes, link 3 gets 4 extra lanes and links 4 and 5 get 1 extra lane.

After this optimization process links 1, 2 and 3 were split in a main road with 4 lanes that goes to destination 2 (through traffic) and a parallel road with 3 lanes that goes to destination 3 (local traffic). This so called unbundling of traffic flows is one of the robustness measures that can be taken. It is shown that this improves the robustness even further.

The quality of the algorithm is shown by comparing the results of the solution algorithm with the results of a full computation of possible network adjustments with a maximum of 4 lanes (3125 combinations). It is shown that the solution algorithm finds the global optimal solution for this test network. Of course, this doesn't prove that the algorithm will find the global optimal solution in other networks, but it does show that the algorithm works properly.

Finally, it is shown that the algorithm converges within an acceptable number of iterations and a sensitivity analysis shows how sensitive the network design is for changes in infrastructure cost and the value of time.

CONCLUSIONS

It is concluded that the solution algorithm that is presented enables us to design robust road networks. In this paper the functioning of the method is shown on a test network. However, the method is made in such a way that it can be applied to large scale networks like the complete area of Rotterdam – The Hague or Amsterdam and surroundings. The solution algorithm combines the best of two worlds. It uses advanced modelling techniques and expert knowledge. By involving the stakeholders during the design a network is designed that is supported by these stakeholders. Furthermore, their detailed knowledge about the network is used to enrich the model results and to interpret those model results correctly.

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