Identification of critical transport infrastructures

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1 Introduction

Since 1990 the annual number of extreme weather and climate related events has doubled in comparison to the previous decade. These events account for about 80% of all economic losses caused by catastrophic events (European Environment Agency (2004), 70). In the course of climate change they are projected to happen even more often. Therefore economic losses due to weather and climate related events will increase, if efforts for prevention and disaster management are stagnating.

Critical infrastructures are especially sensitive to catastrophic events. The Deutsches Bundesamt für Sicherheit in der Informationstechnik (2004) defines critical infrastructures as "organizations and institutions that are important to public welfare; such that failure or disruption of them will result in long-lasting supply bottlenecks, significant disturbances in public security or have other dramatic consequences". Critical infrastructures include among others energy supply, telecommunications and information technology as well as transportation systems. Due to their societal importance, it is crucial to understand how their functionality might be impacted by disruptions.

The paper focuses on transportation infrastructures. In 2005 more than 3500 million tons and nearly 70 billion passengers were transported on German networks. Thus, transportation networks can be considered an intermediate input for satisfying the demand for goods and accomplishing non-market activities. Therefore a disrupted transportation system immediately affects a large spectrum of human activities.

The locations most critical in a network “show the most severe (socio-economic) consequences resulting from network failure at those locations” (Taylor, M. A. P. and D'Este, G. M. (2007), 10). These should be the points of interest for possible disaster mitigation measures.

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The task is now to identify the locations in the transportation network (here: road network) where these consequences are expected to be highest. These locations can be considered the most critical ones. The region of interest in this study is the German state of Baden-Württemberg. The network consists of 683 links representing autobahns and federal roads (Data source: ETIS-BASE). The links contain information on the classification of the road, the number of passenger cars and trucks per day, etc.

2 Identification of critical transport infrastructures

The identification of critical infrastructure is often part of a comprehensive risk analysis. Risk is defined as the product of a hazard (probability of an event with a certain intensity) and the consequences (Berdica, K. (2002)). Figure 1 gives a visual demonstration of the definition.

The consequences are composed of the structural and functional vulnerability of an infrastructure element and the affected values. The structural vulnerability refers to the damages of the structure of an infrastructure element, e.g. which intensity causes a bridge of a certain age and material to collapse. The affected values can be expressed in reconstruction or repair costs. The functional vulnerability is the consequential degree and duration of capacity reduction (e.g. closure of road for 2 weeks). In this case, the affected values consist mainly of detouring costs. Assuming that there is no way to reduce the hazard or it is unknown (e.g. for terrorist attacks) and that constructions are already built and maintained in an optimal way, risk can only be reduced by diminishing the consequences due to the functional vulnerability.

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Approach 1 classifies the road links by the available information, whereas approach 2 utilizes a transport model that accounts for detouring costs as well. The following subchapters explain and demonstrate the approaches in more detail.

2.1 Approach 1: Traffic load

This very straightforward approach only uses the available information on the links. Assuming that Germany’s road network is very dense as long as state, regional, city and other roads are included, it can be reasoned that detouring costs can be neglected when comparing one link disruption to another. In this study the number of passenger vehicles on a link is taken as a reference for the damage potential. The link with the highest number of vehicles would therefore entail the highest consequences if interrupted. The data was clustered into 5 criticality classes using a natural breaks algorithm which is inherent in common GIS software. This algorithm minimizes the variations in a class and maximizes the variations between classes.

2.2 Approach 2: Detouring costs and traffic load

Approach 2 considers additionally the detouring costs. These costs can only be calculated if the origin and destination of the affected trips are known. Rerouting often starts at the trip’s origin and not necessarily close to the disrupted network part. The basis for the calculation is a transport model that can simulate and document changes in network performance. Figure 2 shows the components of a classic four-step transport model. After generating trips on the basis of e.g. population statistics and activity patterns these trips are then distributed to destinations. After diverting the demand to different available modes between an origin-destination pair the vehicles are assigned to paths in the network. The last step is done with a route choice model. Every step needs to be validated by available statistical data.

This study relies on the well calibrated European transport model VACLAV\(^1\). For every road network link in Baden-Württemberg the efficiency drop after removal of the link was calculated. In so doing, the additional time due to detours weighted by the number of affected people was assessed. Based on

\(^{1}\) Transport model developed by the Institute for Economy Policy Research of the University of Karlsruhe. It has successfully been utilized for different EU-projects like TEN-STAC or TRANSTOOLS.
the importance measure of Nagurney, A. and Qiang, Q. (2007) the relative importance of a network link in respect to the damage potential is calculated. As in the previous approach, the results are assigned to 5 classes with the natural breaks algorithm.

2.3 Comparison of results

The identified critical network elements vary in the two approaches. The first approach assigns the highest damage potential to the autobahns A8, the Northern part of the A5 and the A81 as well as the Western part of the A6. These results are self-evident since state roads usually do not bear as many vehicles as autobahns. It can however be expected that in some areas infrastructure redundancy might be able to reduce the damage potential. The second approach seems to capture these effects. The A8 is therefore not considered to be most critical since it has redundant federal roads parallel to it. On the other hand some network elements become more critical due to less redundant infrastructures. This is for example the case for the B30. Both approaches identified the A5 South of Karlsruhe and the A6 West of Heilbronn as most critical. Figure 3 maps the results of the two approaches.

3 Conclusions

The identification of critical road network elements is crucial for narrowing down the focus of risk analysis to areas of possible high consequences due to disruptions in serviceability caused by weather related events or other disturbances. The installation of mitigation measures like real time transport planning can subsequently build on the outcomes.

The study applies two approaches for this undertaking: one very straightforward using information on traffic load and another more complicated one using transport modelling. The identified critical road network parts in Baden-Württemberg differ. While the first approach identifies mainly autobahns, the second approach seems to be more selective and considers also some sections of federal roads to be critical. Although the effort of using a transport model is very high, its contribution towards a better understanding of criteria that increase the damage potential is of great value. It is also essential for the calculation of damages in a risk analysis or in a scenario-based analysis.

The underlying road network of the transport model is currently being simplified and complemented with two more regional road categories so that future calculations can also consider congestion effects and reproduce more realistic detouring costs.

It is also planned to incorporate other factors, which increase the damage potential of a network link. Based on the ideas of the research on risk management indicators, for example Earthquakes and Megacities Initiatives (EMI) (2007), an indicator based approach for the identification of critical infrastructures could be developed. Possible indicators could be regional data on accessibility, the importance of a road link for freight transport, the significance of predominantly transported goods in supply chains, number of commuters or others.
Literature


