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Abstract of the PhD thesis

Evaluation of vulnerability measures on simulated urban road networks

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CONTENTS

1. PREMISES AND JUSTIFICATION

The vulnerability of a road network became the subject of attention since 1995, the The Great Hanshin earthquake in Kobe, Japan. There are many serious threats that can cause urban or rural road networks to fail or to become severely impeded (congestion, natural hazards, structural breakdowns, traffic accidents, traffic management failures, to mention but a few).

Road networks are one of the most important and most complicated part of modern society. Consequently, the reliability of a road network is a decisive factor in terms of market outreach and competition as well as continuity, to ensure a 24/7 operation for the community we live in. Any threat bringing down reliability of the road network means a vulnerable spot (weakness). By urban standards it can cause a minor degradation (i.e. car accident, resulting in queuing, delays and diversions), but the consequences can be more serious if it's a rural case (i.e. when an avalanche blocks the only access road for a long time, even days or weeks).

An average user of the transportation network wants to know the answer of the following question: Can I, knowing the desired time of departure, get from A to B by using a certain route and means of transport, and arrive at a desired time? Or, is there no route or means of travel at all that can take me from A to B at that time of departure or within arriving at the desired time (no user likes this „worst case" answer). A freight hauler thinks a network vulnerable that is easily disrupted, resulting in unpredictable stops and downtime. This is a more difficult problem than a congested network which is *reliably* slow, meaning the goods will arrive, costs are calculable and arriving times are predictable at the destination (though any haul on this kind of network will not be the most efficient one).

In the worst case the unpredictably and quickly collapsing elements or network parts will cause unreliable route plans (even the dinamic ones) for the user and no chance for either a good prediction or an appropriate reaction based on the momentary information of the traffic management system.

Based on my studies the vulnerability of transport networks does not yet have a commonly accepted definition and/or methodology, and the scientific base is missing behind the discussion and the problem itself. Most of the authors agree though that the key to vulnerability research is the analysis and study of the *impacts* of the different threats to the network (and not the threats themselves).

2. AIMS AND METHODOLOGY

The concept of this thesis is to study the correlation of some (i.e. traffic, environmental, network) parameters and the vulnerabilty metrics given by some authors brave enough to make a suggestion for the context before anybody else.

The base and the most important tool of my studies was the database a network simulation modell. The database contains all the data was generated during the simulation period, so it is possible to analyse the connection between any given parameter or set of the parameters (i.e. speed, follow-up distance, density, etc.) and the metrics given by the theory waiting for to be proved (i.e. weakness, exposure, importance, etc.).

The base of the simulation itself is a continuos data flow of certain parameters like follow-up distance as a function of lane speed and density coming directly from a special software processing traffic surveillance camera pictures.

The modell can be calibrated with the momentary situation of the network with the help of this online data processing system, so all the vulnerability calculations will include the most appropriate data available at the moment.

There were 5 questions of mine to find the answer for while analyzing how useful some vulnerability metrics are to evaluate some problems of network management and development. The questions were as follows:

1 Is it possible to find any context between the parameters read from the pictures of the traffic surveillance cameras and how can we use them in the network simulation model?
2 Which metric of vulnerability is the most useful for a certain group of users (i.e. travelers are mostly interested in travel time)?
3 Is it possible to influence the vulnerability in the future using traffic technology solutions using the momentary parameters above?
4 Is it possible to make an order for getting over the vulnerabilities using any of the known metrics?
5 Is there an appropriate metric of vulnerability for helping the decision between certain development scenarios?

To find the answer to these questions above, we need to

- Build an appropriate network model
- Find traffic parameters for each metric of vulnerability
- Analyse the correlation between the traffic parameter and the metric of vulnerability
- Find out how is it possible to use the context proven either in decision making or route planning and network development

Analysing the future impacts of possible threats the vulnerability analysis must focus on three important questions:

- Where is it vulnerable?
- Vulnerable to what?
- How is it vulnerable?

In some cases there is no chance to find an answer for a question of these three without answering at least another, sometimes all. On the other hand, when trying to draft the answer it is easy to realize that different words sometimes mean the same thing when trying to explain, and in worse cases we use the similar word for a different approach. SO WHAT IS VULNERABILTY?

The key to continue the search for the final 5 answers was to study all the possible known aspects of vulnerability. For the first try I analysed the link weakness index showing „how important each link is for the overall set of origin/destination pairs, by assessing how many o/d paths share the same link" (Di Mangi, 2005). By weighing the *weakness index* with travel demand, the **link exposure index** can be calculated for each link. For the second try I used the increase in **generalised travel costs** weighted by the satisfied or unsatisfied demand when network links are closed as a measure of vulnerability. *Importance* reflects the *significance* of each link with regard to the network, and *exposure* reflects the increase in travel cost for a given location within the network. Together these measure provide substantial information as where the most vulnerable (exposed and or/important) links in the network are (Jenelius et al., 2006). The third try is a **weighted multi-criteria decision approach**, where „link closures or degradations are assessed by various categories of effect and the severity of the impact, thus allowing for the assessment of individual effects or impacts" (Husdal, 2005).

To analyse the vulnerability metrics I had to build a transportation network model which prvides all the data needed to find all the contexts wanted. My model is a grid of 10 rows and 10 columns with a link length of 1000 meters (see *figure 1*). This supposed to be the main road network of a city with only multilevel and signalized intersections. There are 9 different scenarios of geometry (the type of the intersection, the number of lanes and the speeds are different in each) supposed to mean 9 different levels and states of development in the life of a city.

I assigned my network model with several matices to have as many states of all the elements as possible. After approximately 8750 assignments on the 9 scenarios of the network, I tried to find the connection between the physical meaning of the vulnerability metrics and the traffic parameters given by the model.

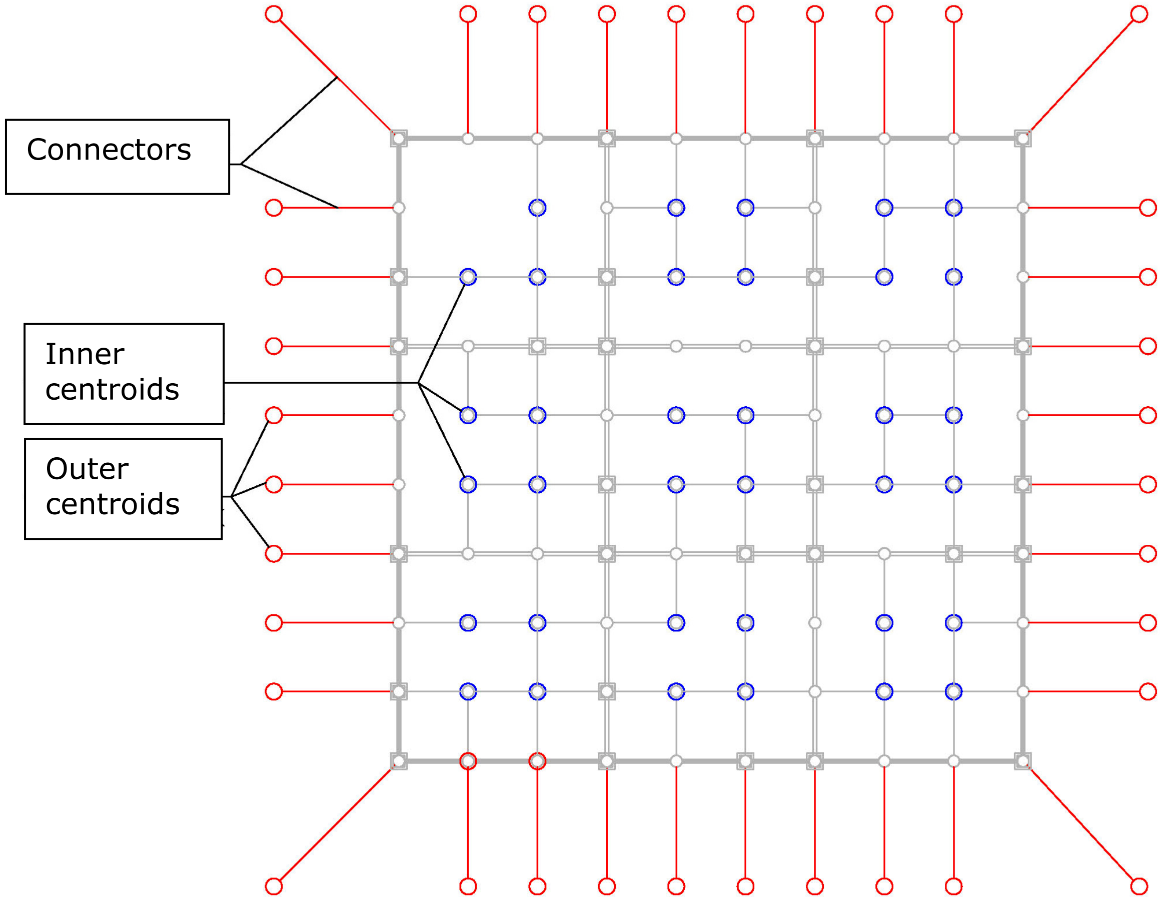


Figure 1 Network model geometry

3. RESULTS

RESULT 1

Without feedback to the Traffic Control System on the inner links of the simulated main road network I could not prove any effect of entering vehicle distribution on the traffic parameters if the distribution was exponential, pareto II or normal (see *Figure 2*).

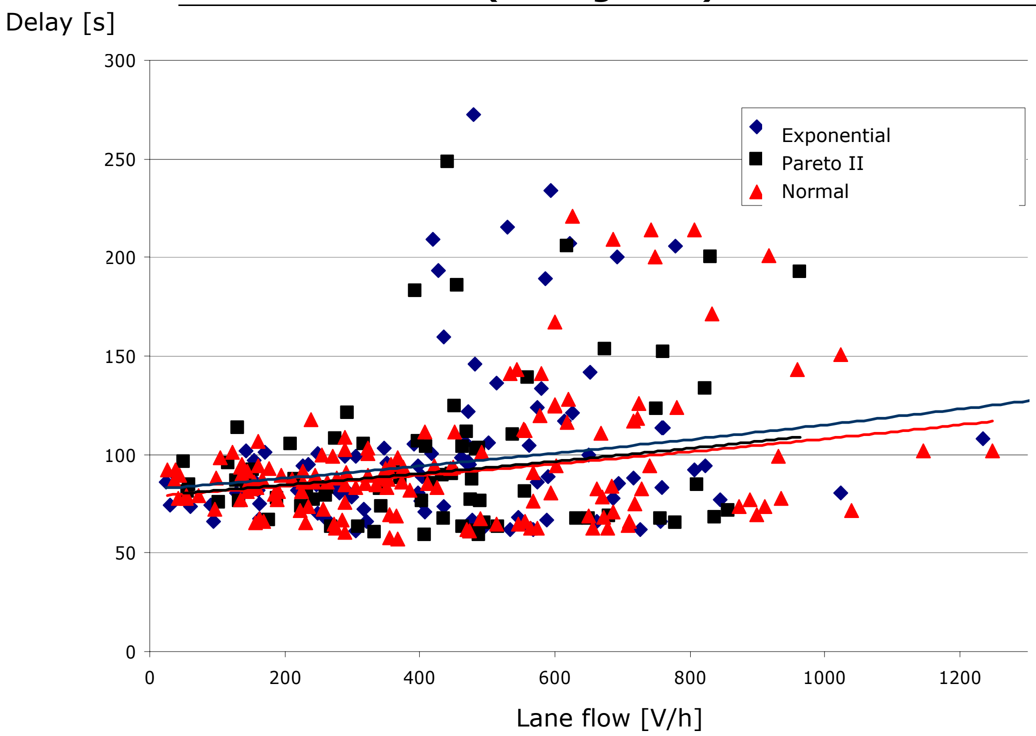


Figure 2 Volume-Delay functions in case of different vehicle distribution (an example)

RESULT 2

Based on the results of my research the correlation between the link exposure index and the total travel time of the network shows functional relation (R^2>0,8077) if the link exposure index is under 72 000 and the link is in operation (see *Figure 3*). [5]

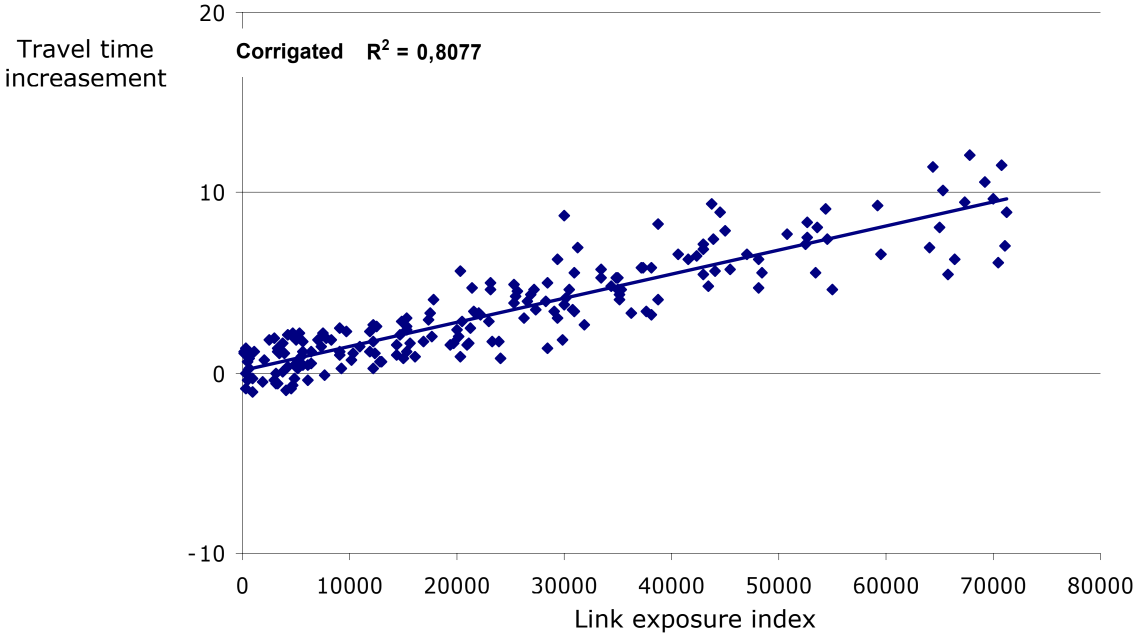


Figure 3 Link exposure index in more than 60 % of the cases

RESULT 3

Based on the results of my research the correlation between the importance of an element calculated by the generalized transportation costs method as the travel time increasement of the network and the performance (P) of the element is very strong (R^2>0,9 in the 85 % of the cases) if P< 200 000 vehicle seconds in an hour (see Figure 4). [13]

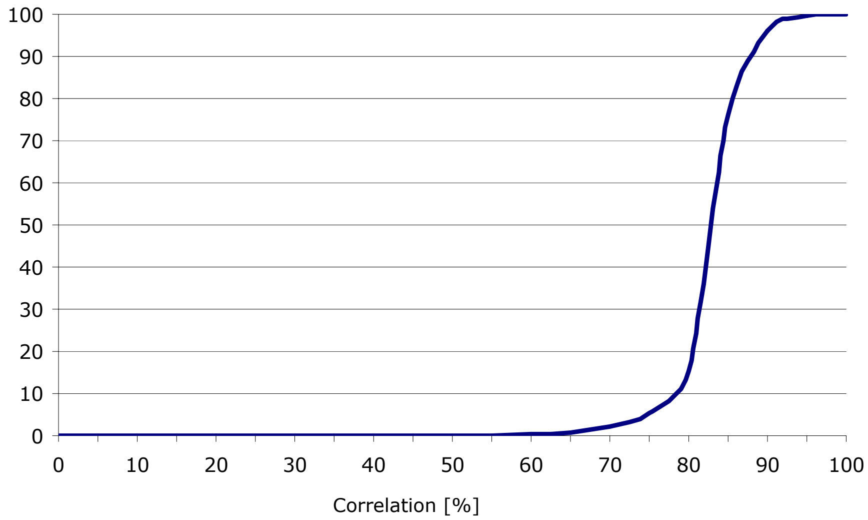
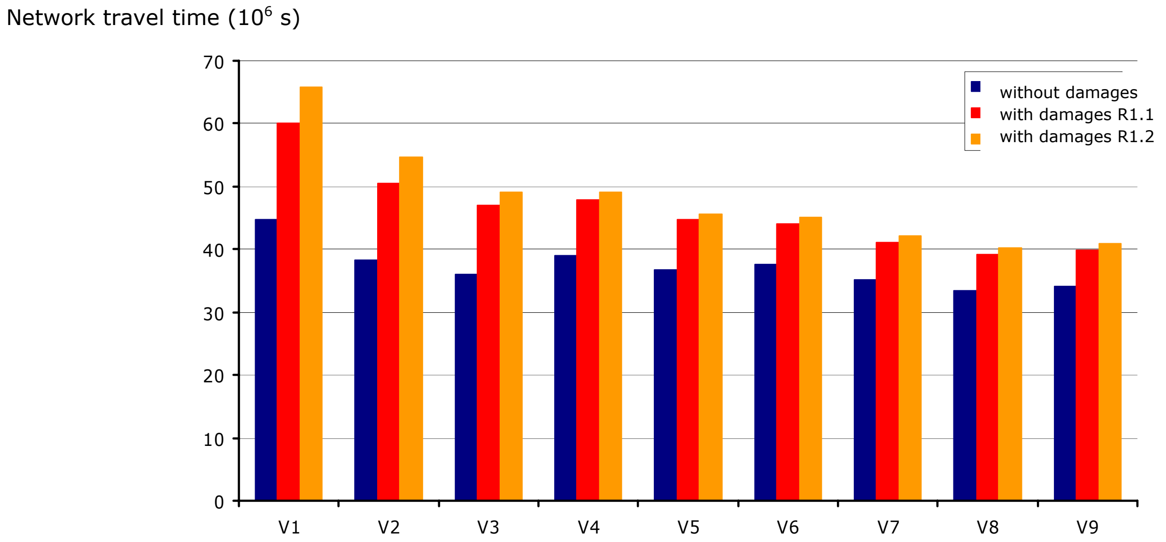


Figure 4 Cumulated relative frequency (P<200 000 Vs/h)

RESULT 4

Based on the results of my research it is possible to make an order for getting over (or causing) certain damages using generalizing the critical scenario method to get the travel time increasement of the network. [3]



…nes for each combination of scenarios and damages

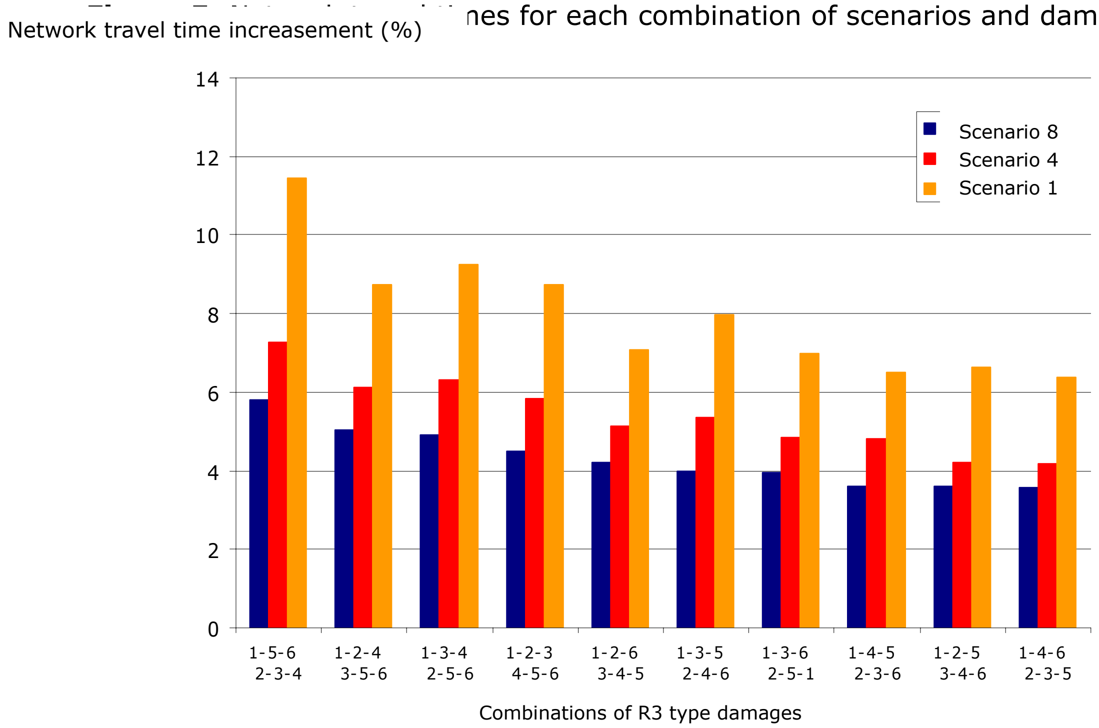


Figure 6 Relative network travel time increasement on 3 scenarios for 6 damages

RESULT 5

Based on the results of my research it is possible to make an order for developments' normalized costs with the generalized transportation costs method based on the travel time increasement. [3]

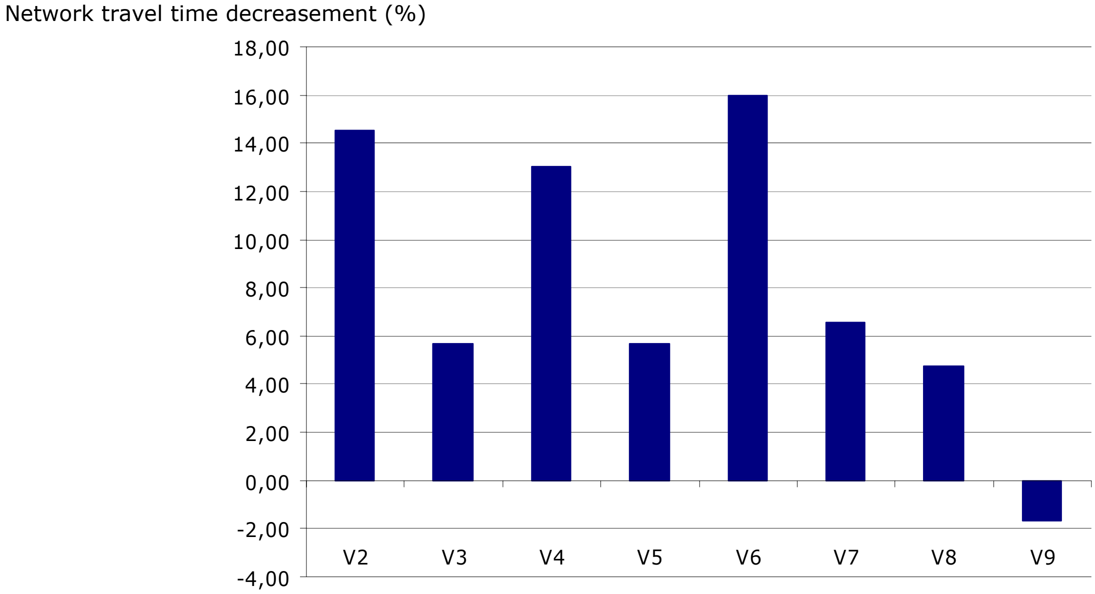


Figure 7 Effect of network development on the network travel time by scenarios

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