Link-level Vulnerability Indicators for Real-World Networks

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Abstract

Literature proposes link-based indicators as predictors of the delay caused by a blockade on a particular link. This paper cross-compares these indicators and compares them with the result of a full simulation. The indicators predict different links to be vulnerable. Furthermore, the indicators do not provide a good indication of the delay of a blockade, partly because traffic dynamics (including spillback or blocking back) are not well included in the indicators. A linear combination of different indicators does not increase the performance either. Once more than one indicator is included in the fit, the predictive value of the combination of the indicators is lower than the predictive value of one indicator due to over fitting.

Methodology

- In literature: 9 link-based criteria predicting impact of a blockade

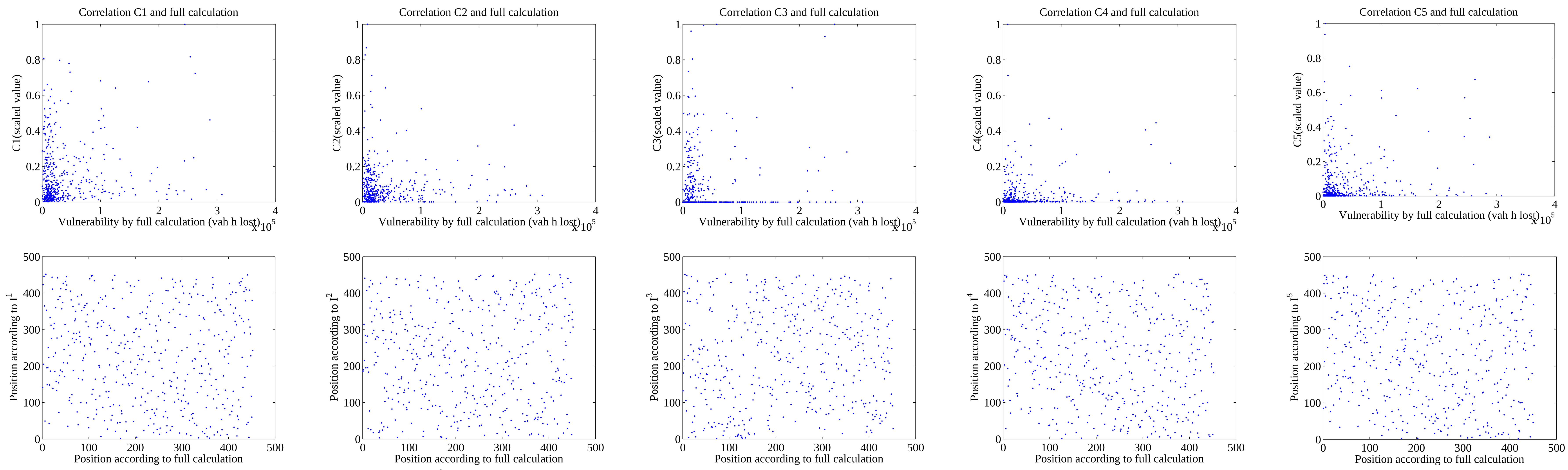
=> Calculate for 3 networks (11, 150 and 468 links)

=> Cross-compare values

- 468-link network: also dynamic traffic simulation

=> 468 values for the delay caused by blockades at different sites

=> Fit these delays with the values of the indicators.



$I^1 = q/(1-q/C)$ $\quad I^2 = 1/T_b$ $\quad I^3 = I_i^1 \cdot \vartheta\,(q-2500)$ $\quad I^4 = I^1 \cdot q$ $\quad I_i^5 = I_i^2 \cdot q_i \cdot \sum_{\text{upstream links } j \text{ of } i} I_j^1$

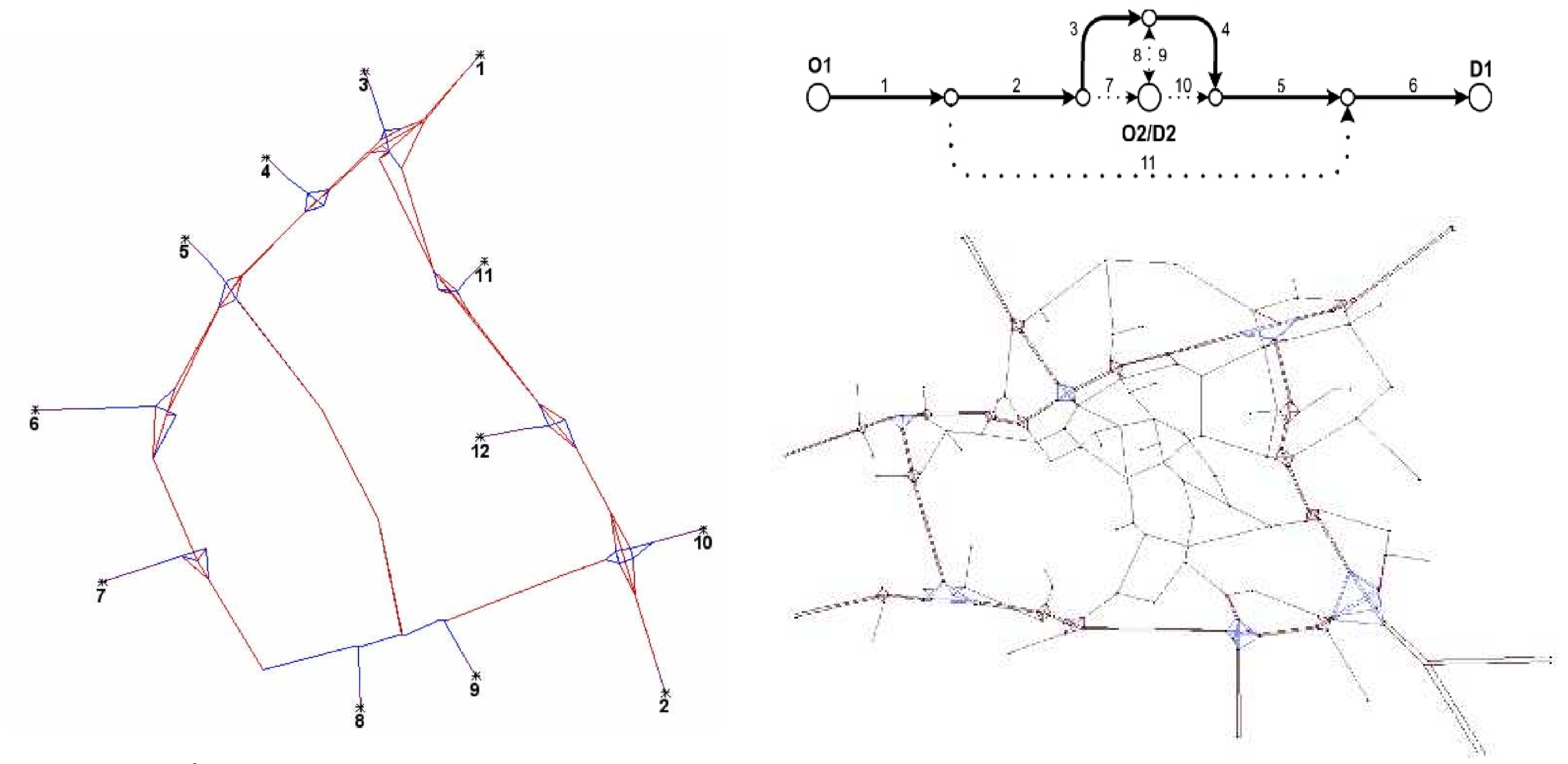
The correlation between the indicator values and the full calculation (top row) and between the predicted ranks and the calculated ranks (bottom row)

Results

- Different indicators indicate different links a vulnerable.

=> complementary?

- Also combination of indicators does not indicate the most vulnerable links
- Alternative: include the most vulnerable links according to each of the indicators
- Result: include many links since all indicators differ



The considered networks

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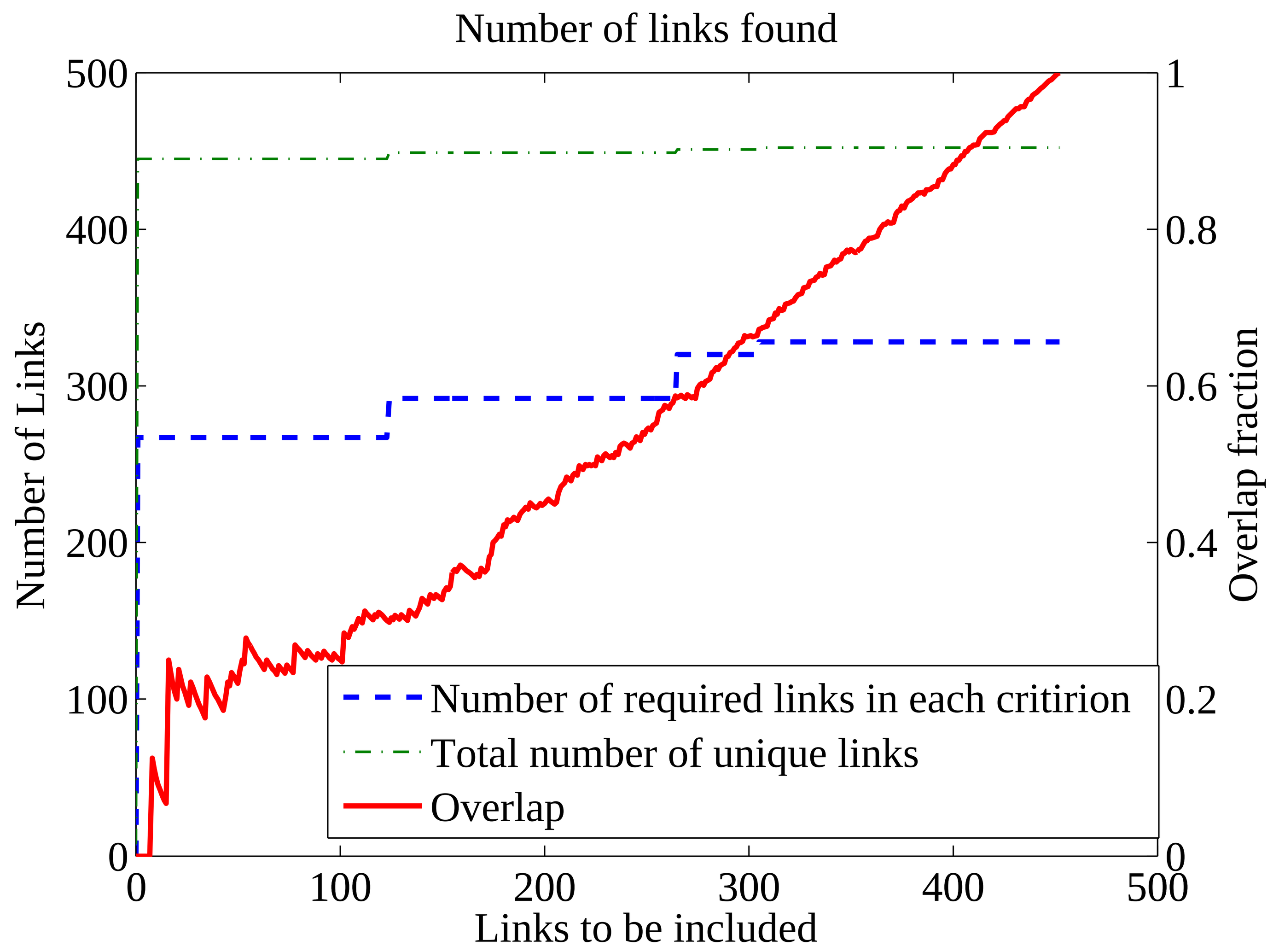
Combinations

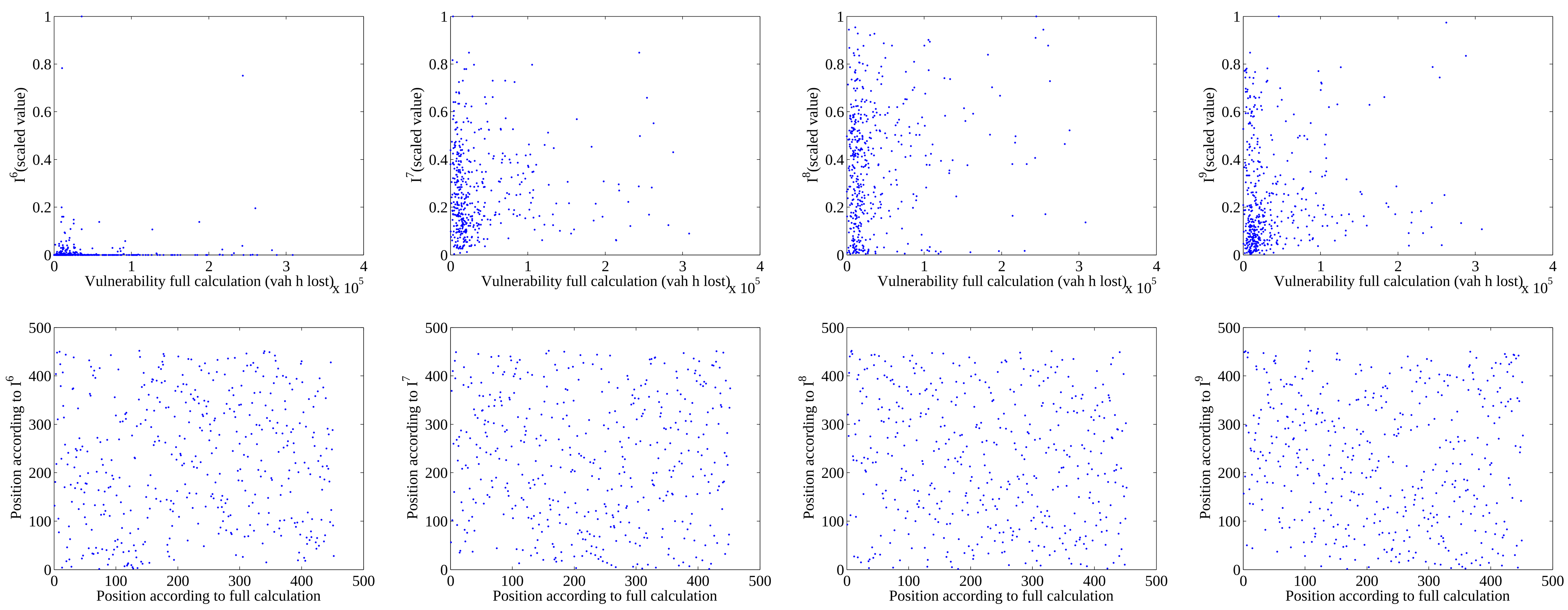
- 468 values of the impact calculated with a dynamic traffic simulation program (large network).
- Delay is estimated by $\widetilde{D} = \sum_{\text{indicator i}} a_i C_i$
- Tried for all possible combinations of indicators
- 9 indicators, so 2^9=512 combinations
- Coefficients a_i optimized on a calibration set (2/3)
- Combination tested on validation set (1/3)

=> Combining hardly reduces the residual error

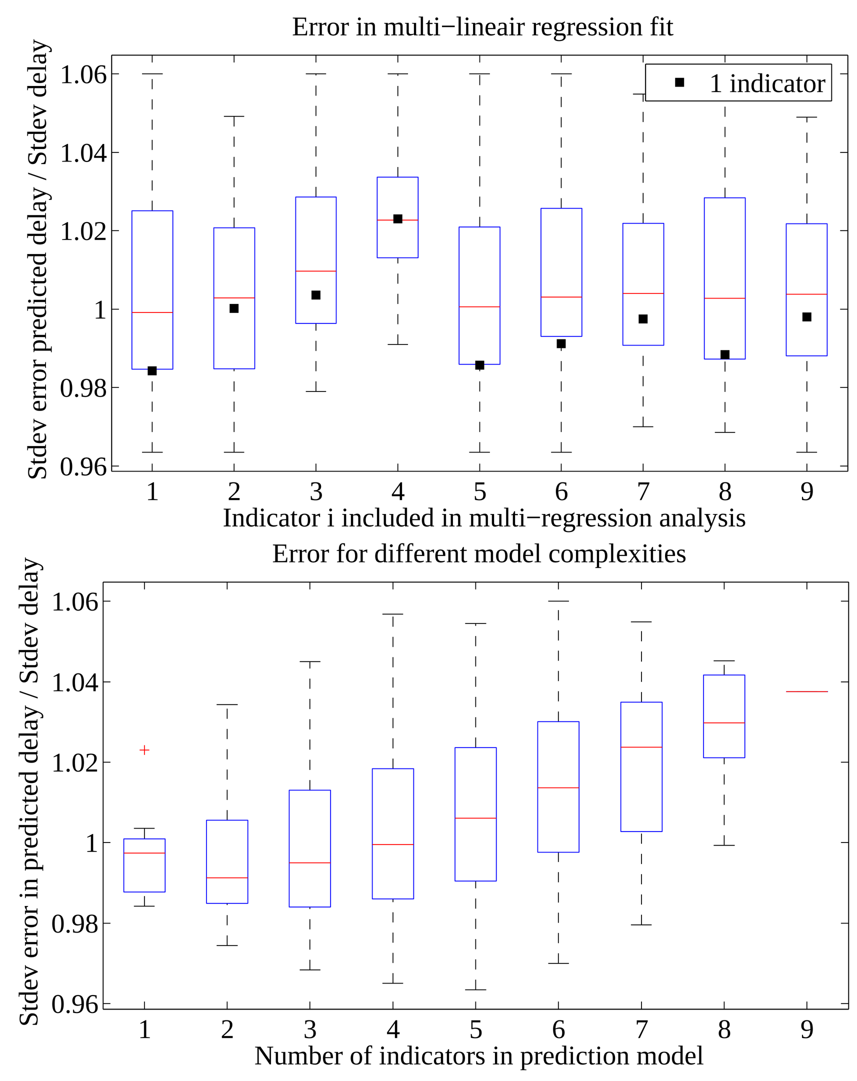
=> Including more than one indicator increases the error

=> over fitted





$I_i^6 = I_i^3 \cdot q_i \cdot \sum_{\text{upstream links } j \text{ of } i} I_j^1$ $\quad I^7 = \sum_{\text{upstream links } j \text{ of } i} I_j^1$ $\quad I^8 = \frac{q}{C}$ $\quad I^9 = q_i - C_i^b$



Results of fits of combinations

Discussion

The influence of a blockade stretches further than the link where the blockade occurs. Network dynamics should therefore taken into account. In practice, also alternative routes play a role. This is insufficiently captured in the current indicators. Link-level indicators are therefore unable to indicate the vulnerable links. Possible alternatives are indicators which include alternative routes, or otherwise a complete simulation of the network.

Conclusions

Current link-based indicators do not provide an insight into the vulnerability of blockades in a network. Moreover, they cannot be used to select a subset of possible vulnerable links. Network effects play an important role in the real vulnerability. Therefore, if one looks for an indicator for vulnerability, it needs to include these effects.