IJCSS International Journal of Complex Systems in Science

Int. J. Complex Systems in Science
vol. **5(1)** (2015), pp. 1–3

Identifying Critical Components in Complex Gas Distribution Networks

Daniël Worm[1,†], Noëlle Fischer[1], Willem Pino[1,2] and Robert Kooij[1,3]

[1] *Performance of Networks and Systems, TNO, the Netherlands*

[2] *Department of Information and Computing Sciences, Utrecht University, the Netherlands*

[3] *Faculty of Electrical Engineering, Mathematics and Computer Science, Delft University of Technology, the Netherlands*

Abstract. We propose graph theoretical resilience metrics for the identification of critical pipes in gas distribution networks, i.e. pipes whose failure would have the greatest impact in terms of gas demand not delivered. These metrics are applied to a case study and compared to realistic gas flow simulations that incorporate pipe failures. We succeed in identifying the critical pipes by using a metric closely related to efficiency.

Keywords: Resilience metrics, Gas distribution networks, Efficiency
MSC 2000: 05C40, 90B10, 90B25

[†] **Corresponding author:** daniel.worm@tno.nl
Received: July 27th, 2015
Published: September 30th, 2015

1. Introduction

There is a growing need in society to increase resilience of critical infrastructures. In this paper we focus on gas distribution networks. Natural gas consumption forms 20% to 40% of the total energy consumption in Europe (Eurostat, 2014). Therefore, disruptions in gas distribution networks may have vast economic and social consequences. However, scientific work on the resilience of gas networks is rare [1].

Therefore, we propose metrics that can be used to quantify resilience of gas distribution networks. Our primary goal is the identification of critical pipes in the network, i.e. the pipes whose failure would have the greatest impact in terms of gas demand not delivered. This knowledge can help gas distribution operators in supporting replacement and repair decisions in their ageing distribution networks. We conclude that using a metric closely related to efficiency is most effective in identifying the critical pipes.

2. Case study: Gas distribution network of Texel

Texel is a Dutch island, with a surface of about 160 km^2 and approximately 13000 inhabitants. Its gas distribution network data was supplied by Alliander, the largest Dutch Distribution System Operator. The gas enters Texel from the mainland at one single distribution node and is distributed further over three pressure levels: 8 bar, 3 bar and 100 mbar. The network consists of 20567 nodes and 20749 links (pipes). The 8 and 3 bar subnetwork (of 1845 nodes and 1851 links) is the important part since it transports the highest amounts of gas, while the 100 mbar pipes are used to connect the consumers. Therefore we focus our search for critical pipes in the 8 and 3 bar subnetwork.

3. Resilience metrics

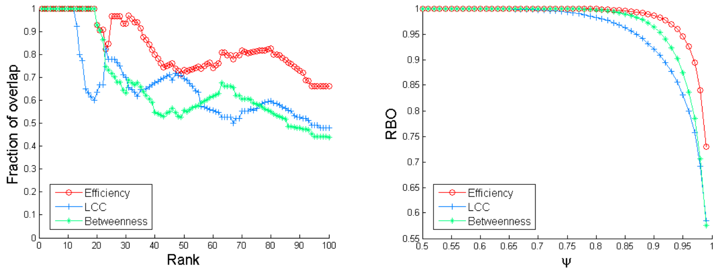
Based on the literature [2] we have chosen three potential metrics for identifying critical pipes: betweenness, efficiency and largest connected component (LCC) size. We adjust these metrics based on specifics of gas distribution networks: instead of considering the all-pairs shortest paths in betweenness and efficiency, we only consider paths from the main distribution node to consumer nodes. Instead of considering the size of the largest connected component, we consider the size of the component connected to the main distribution node. Furthermore, we assess efficiency and LCC by relative change in the metric value after link removal, such that a score for each link is obtained.

4. Results and Conclusions

An accurate gas flow simulation model is used to identify the most critical pipes in the Texel network, by simulating the effect of pipe failure (link removal) in terms of gas demand (not) served to the consumers for each of the higher pressure pipes in the network. With the aim of assessing how successful the considered metrics are in such identification of ciritical pipes, we compare them to the simulations.

First we look at the fraction of overlap, i.e. the relative size of the intersection between the rank-ordered simulation results and each of the three metrics at different depths in the rankings (up to a hundred), as displayed in Figure 1a. The first ten to twenty most critical pipes are correctly identified by each of the three metrics. The fraction of overlap gradually decreases hereafter, with efficiency achieving the greatest overlap size at deeper ranks.

Figure 1b shows Rank Biased Overlap (RBO) [3], a (top)weighted average over the fractions of overlap at different depths for different values of the top-weight parameter ψ. It is evident from Figure 1b that all three metrics perform



(a) Fraction of overlap (b) Rank Biased Overlap

Figure 1: Comparison of metrics to simulation results

very well in terms of RBO. In the literature $\psi = 0.9$ is suggested as a typical choice [3]; for this value the RBO of the efficiency is 0.986.

In addition, the required computation times for all metrics are much shorter than the time needed for the simulations. The efficiency clearly outperforms the other two metrics in both fraction of overlap and RBO. Therefore we suggest to use this metric for identification of critical pipes in gas distribution networks.

References

[1] R. Carvalho, L. Buzna, F. Bono, M. Masera, D.K.Arrowsmith and D. Helbing, Resilience of Natural Gas Networks during Conflicts, Crises and Disruptions, *PLoS ONE* **9** 3, e90265 (2014).

[2] M.E.J. Newman, The Structure and Function of Complex Networks, *Siam Reviews* **45**, 167-256 (2003).

[3] W. Webber, A. Moffat and J. Zobel, A similarity measure for indefinite rankings, *ACM Transactions on Information Systems* **28** 4, 1-38, (2010).