Aalto-yliopisto
Perustieteiden korkeakoulu

The impacts of correlated supplier disruptions in supply networks

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Introduction

- Supply network is the network through which a company gets and delivers goods and services
  - Supply chains are strategically important
- Disruptions in a supply network are events that can prevent a company from operating
  - Events such as earthquakes (Käki et al., 2015) and floods (Kim et al., 2015) might cause a disruption
- What happens if the disruptions are correlated?

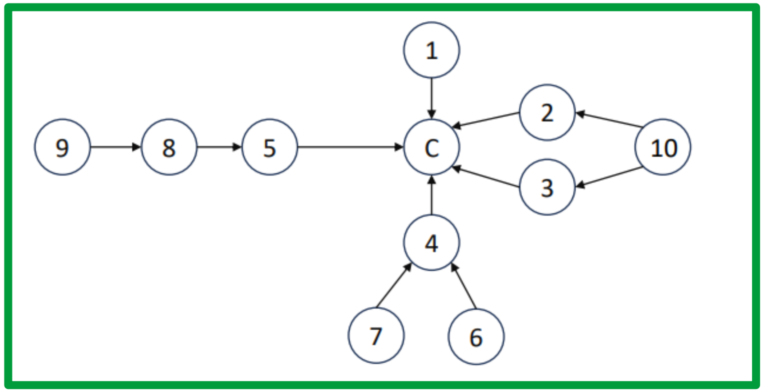

Figure 1: An example of a supply network (Käki et al., 2015).

Elements of a supply network in our study

Node
An entity in a supply network (e.g. A company).

Arc
A connection between nodes in the supply network (e.g. A connection between companies)

Objective

- Examine how the correlation between the disruptions of two suppliers impact the disruption probability of a focal company

Methodology

Probabilistic Risk Assessment (PRA) - approach

- Failures and their probabilities are estimated quantitatively (Stamatelatos, 2000)

Bayesian networks

- The supply network is modelled as a Bayesian network
- The disruption probability of node *i* in Figure 2

$$F_i = \alpha_i + \alpha_j \ \beta_{i|j}(1 - \alpha_i)$$

- In larger networks, this disruption probability is more difficult to derive

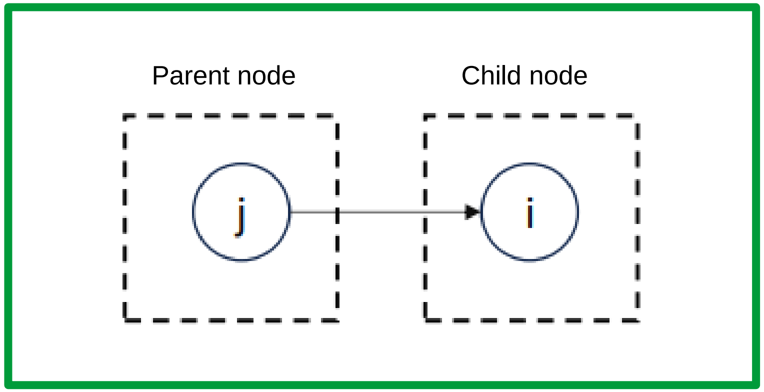

Figure 2: A simple supply network (Käki et al., 2015).

F_i	$\beta_{i\|j}$	α_i
Probability of disruption of node *i*	Probability that a possible disruption propagates from node *j* to node *i*	Probability that node *i* fails indepen-dently

Methodology

- Monte Carlo Simulation
  - The binary state X of each node is generated from the binomial distribution
  - From these states, the state of the focal node is derived

$$X_1 = \max(X_2 \cdot X_{1|2}, X_3 \cdot X_{1|3}, \text{Internal state of node 1})$$

  - The network state is sampled 100 000 times in each simulation
- Correlation
  - Pearson correlation coefficient between the states of the correlated nodes is calculated

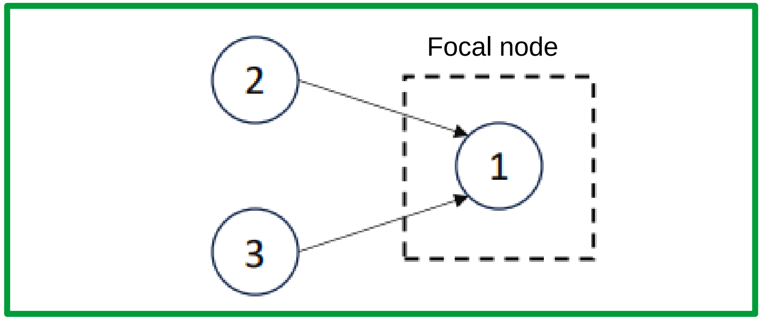

Figure 3: A supply network with three nodes and two arcs (Käki et al., 2015).

Binary states

State X_i = 0
Node *i* is operational

State X_i = 1
Node *i* is disrupted

Methodology

- Implementation of correlation
  - An auxiliary node *s* and auxiliary arcs from node *s* to nodes 6 and 7 are added to network
  - Node *s* is connected to nodes 6 and 7 via conditional probabilities:

$$F_6 = P(6|s)P(s) + P(6|\bar{s})P(\bar{s})$$

$$F_7 = P(7|s)P(s) + P(7|\bar{s})P(\bar{s})$$

  - This sets up the correlation between disruptions of nodes 6 and 7
- Parameter modification
  - Parameters $F_6, F_7, \beta_{4|7}$ and $\beta_{4|6}$ are modified to determine for which parameter values the correlation has impact on the disruption probability of focal node C

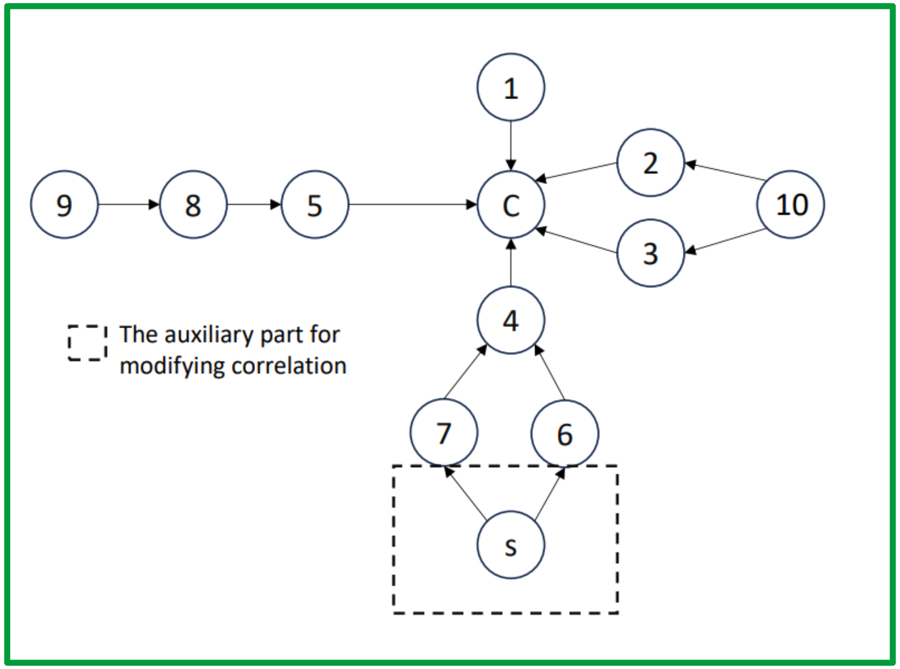

Figure 4: Network used in our simulations (Käki et al., 2015).

Simulation results

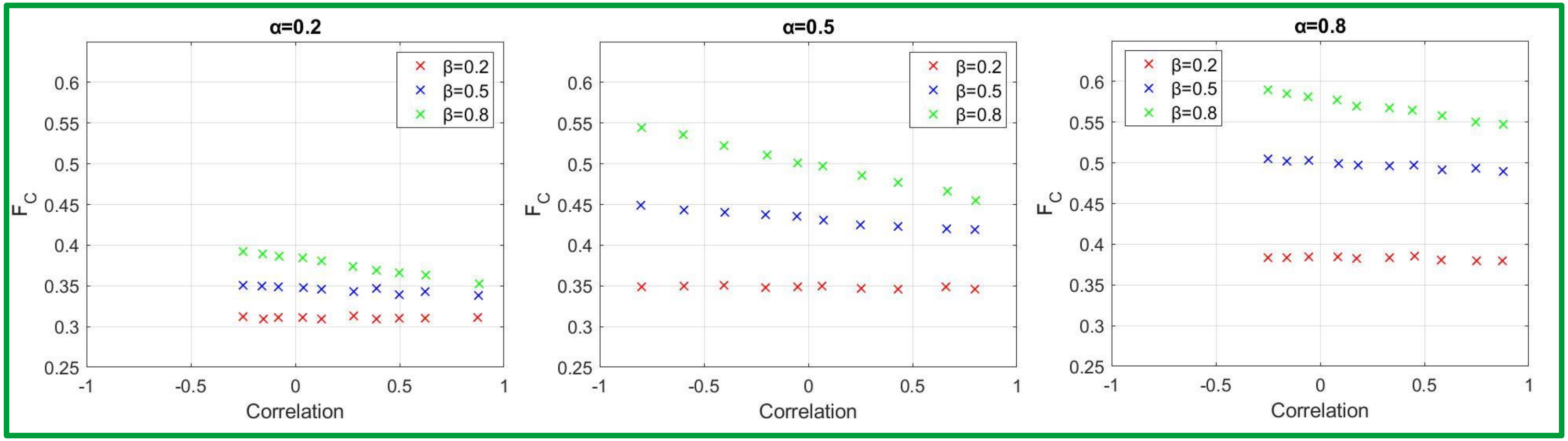

Figure 5: Disruption probability of focal node C as a function of the correlation between disruptions of nodes 6 and 7 with different parameters α and β.

Parameters α and β

The higher the α or the β, the higher the F_C

Impact of correlation

When the value of parameter β is high, F_C decreases as the correlation increases

Simulation results

	α = 0.2			α = 0.5			α = 0.8		
β	0.2	0.5	0.8	0.2	0.5	0.8	0.2	0.5	0.8
High correlation	0.875	0.877	0.880	0.800	0.799	0.802	0.874	0.876	0.877
Low correlation	-0.250	-0.249	-0.250	-0.800	-0.802	-0.799	-0.250	-0.251	-0.250
F_C with high correlation	0.311	0.338	0.353	0.346	0.419	0.455	0.380	0.489	0.547
F_C with low correlation	0.312	0.351	0.392	0.349	0.449	0.545	0.383	0.505	0.590
Difference of F_C	-0.001	-0.013	-0.039	-0.004	-0.031	-0.090	-0.004	-0.015	-0.042
Relative difference of F_C	-0.36 %	-3.65 %	-9.95 %	-1.01 %	-6.80 %	-16.52 %	-0.94 %	-3.02 %	-7.18 %

Table 1: Simulation values of FC with high and low correlations with different parameter values.

What do the results imply?

1. When the probability for the disruption propagation from the nodes facing correlated disruptions (β) is high, the higher the correlation between disruptive events is, the lower the probability of disruption of the focal node C.

2. When the probability for the disruption propagation from the nodes facing correlated disruptions (β) or disruption probability of these nodes (α) increases, the disruption probability of the focal node C increases.

Discussion

Restrictions for our model and results

Propagation of disruptions
- Disruption propagation from only one parent node is sufficient to disrupt the child node
- Disruptions can propagate only from parent nodes to child nodes

Size of the network
- Supply networks are typically large (Käki et al., 2015)

Correlated nodes
- These nodes were at the same position in the network
- Only two correlated nodes were considered

What should be studied next?
- Different structures for the propagation of disruptions
- More than two correlated nodes in the network

References

- Anssi Käki, Ahti Salo, and Srinivas Talluri. Disruptions In Supply Networks: A Probabilistic Risk Assessment Approach. Journal of Business Logistics, 36(3):273–287, 2015.
- Yusoon Kim, Yi-Su Chen, and Kevin Linderman. Supply Network Disruption And Resilience: A Network Structural Perspective. Journal of Operations Management, 33:43–59, 2015.
- Michael Stamatelatos. Probabilistic Risk Assessment: What Is It And Why Is It Worth Performing It. NASA Office of Safety and Mission Assurance, 4(05):00, 2000.

Annex

- When the value of parameter α is high or low (e.g. 0.2 or 0.8), the correlation cannot be very negative
- E.g. when α = 0.2, the nodes facing correlated disruptions are disrupted in around 20% of the network states
  - High negative correlation requires that the states differ in many network states
  - Even though disrupted states occurred in different network states, there would be around 60% of the network states, where these states are the same

State	1	2	3	4	5	6	7	8	9	10
X_6	1	1	0	0	0	0	0	0	0	0
X_7	0	0	1	1	0	0	0	0	0	0

Table 2: Example of the possible states of nodes 6 and 7 when α = 0.2.