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IARIA

Stochastic Supply Chain Costs Minimization under Disruption Risks and Determination of Critical Nodes

Keynote IARIA Congress 2023

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CV Tim vor der Brück

- Software Developer ISO-Group
- Lecturer for Data Science and Linux at FFHS (Distance University Switzerland)

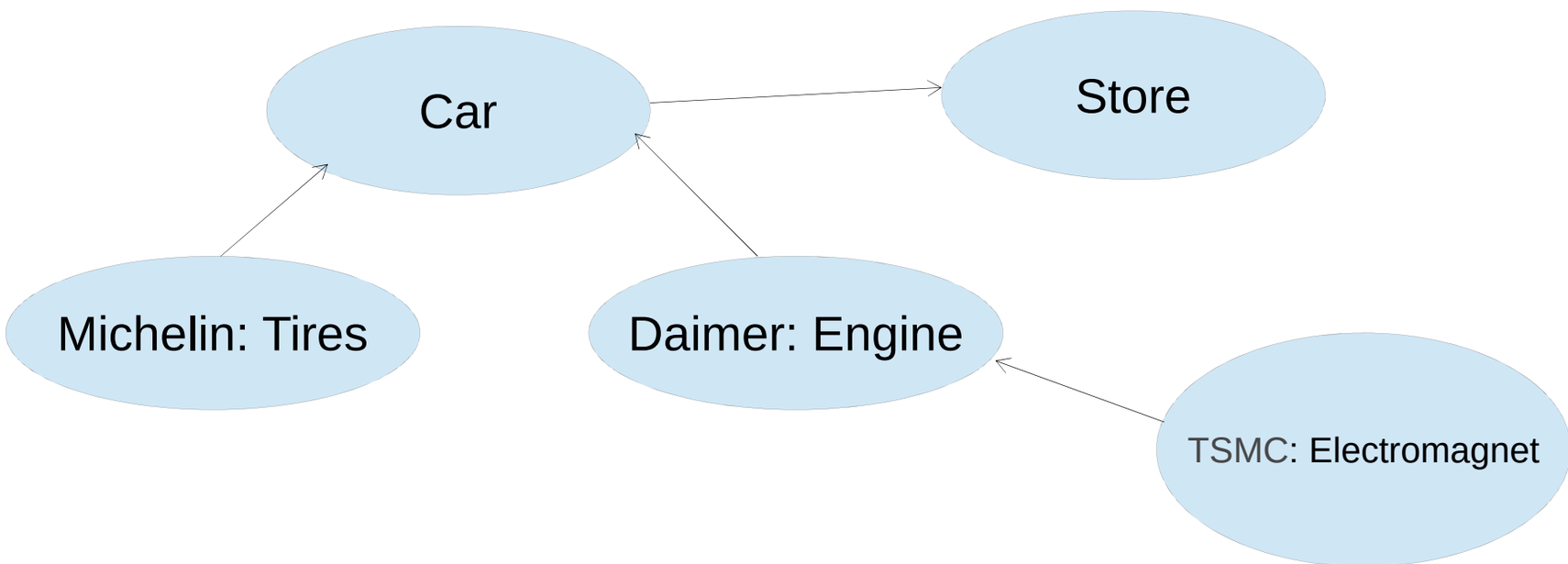
Former Stations:

- Study of computer science at Saarland University, Germany
- DFKI, German Meteorological Service
- PhD Distance University of Hagen
- PostDoc Frankfurt University
- Senior Researcher at Lucerne University of Applied Sciences and Arts

Supply Chain

A supply chain can be represented by a graph

- Nodes: locations / items
- Edges: transportation links between locations



Risks

A supply chain can be affected by several risks

- Disruption risks
- Price escalation risks
- Inventory and scheduling risks
- Technology access risk
- Quality risks

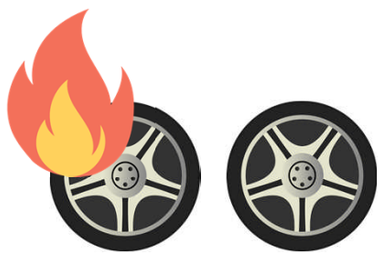
Example Disruption Risk

Supplier 1

Supplier 2

Supplier 3

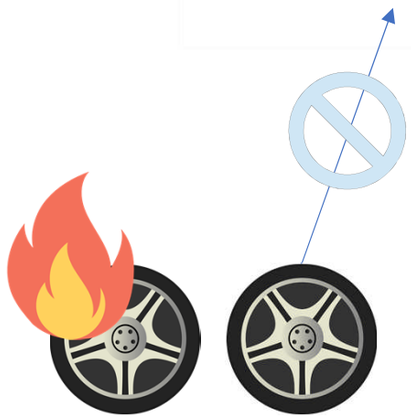
Dealer



Supplier 1

Supplier 2

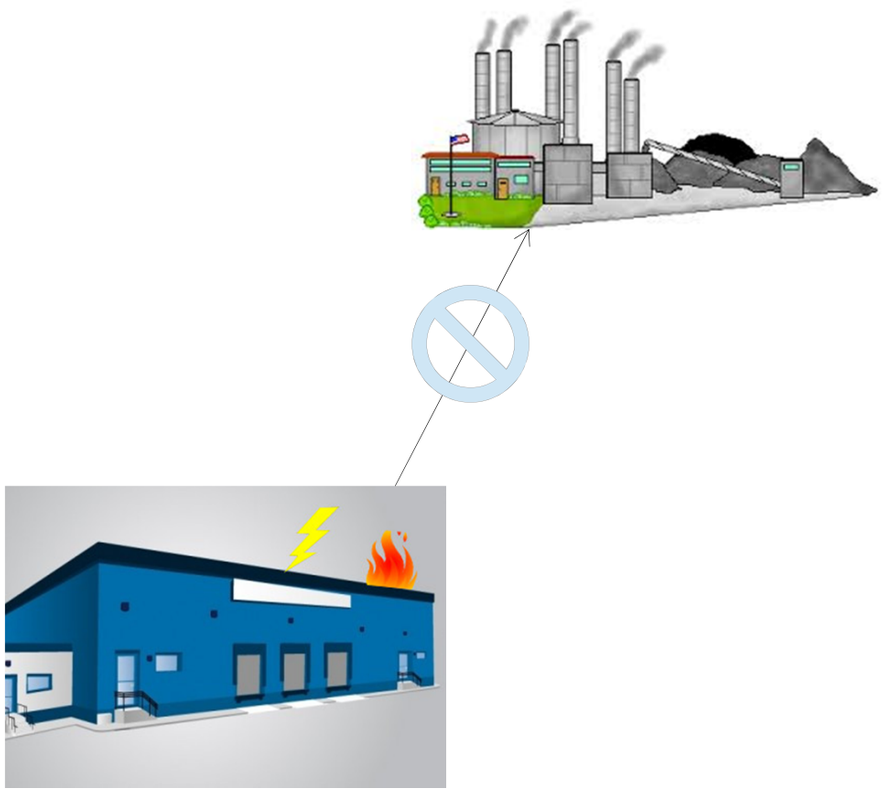
Dealer



Supplier 1

Supplier 2

Disruption risks

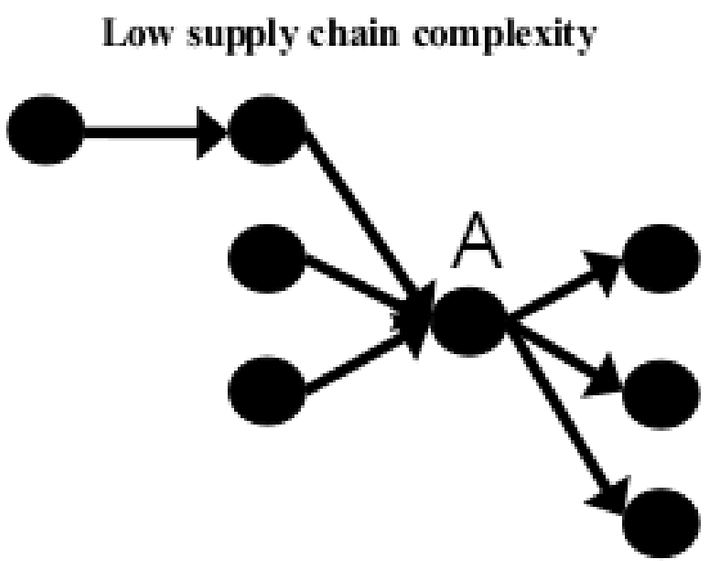


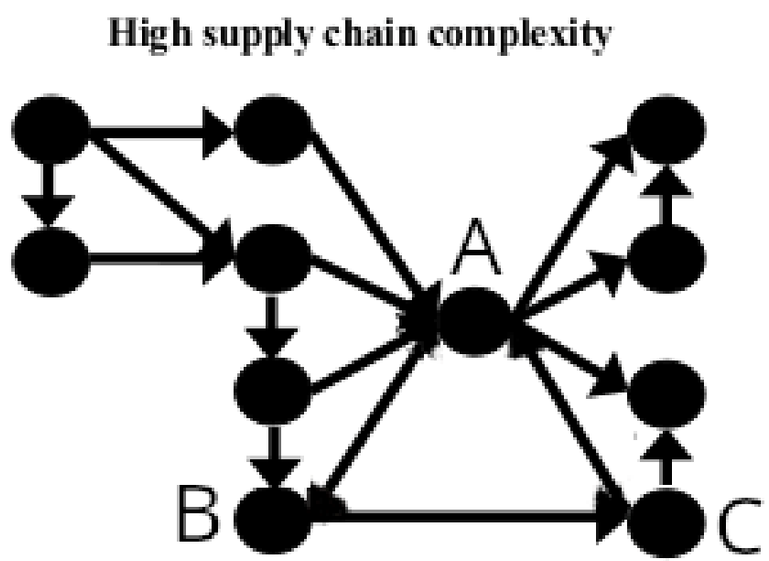
Possible disruption risks:

- Natural disasters like earthquake or volcano eruption, lightning strike, fire
- Political risks like Brexit
- Labor strike
- Sabotage
- Cyber-attack, burglars

Graph-based supply chain risk measures

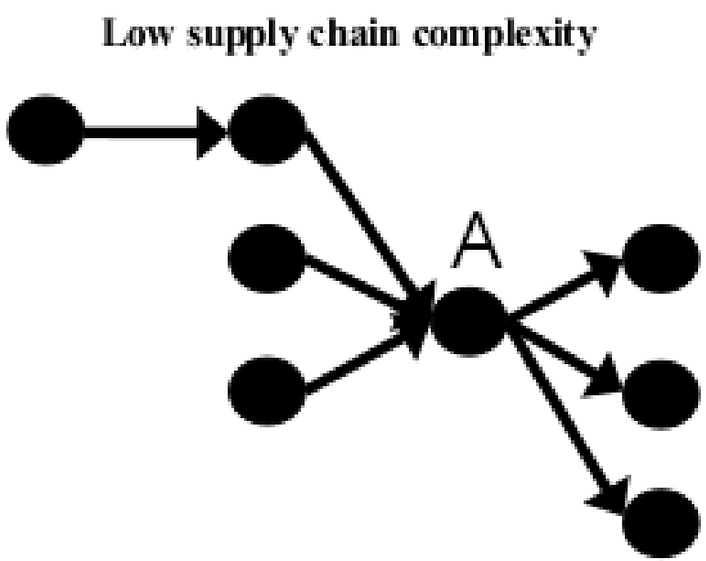
- Complexity
- Density
- Critical Nodes

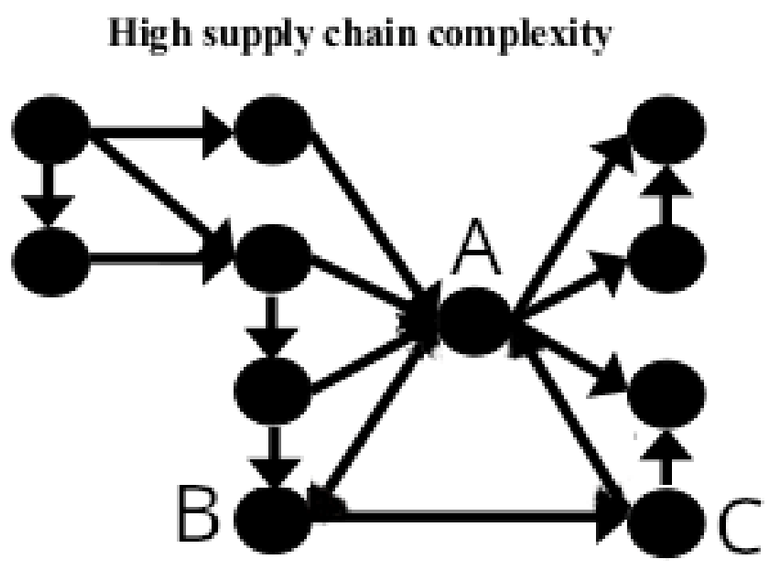




Complexity

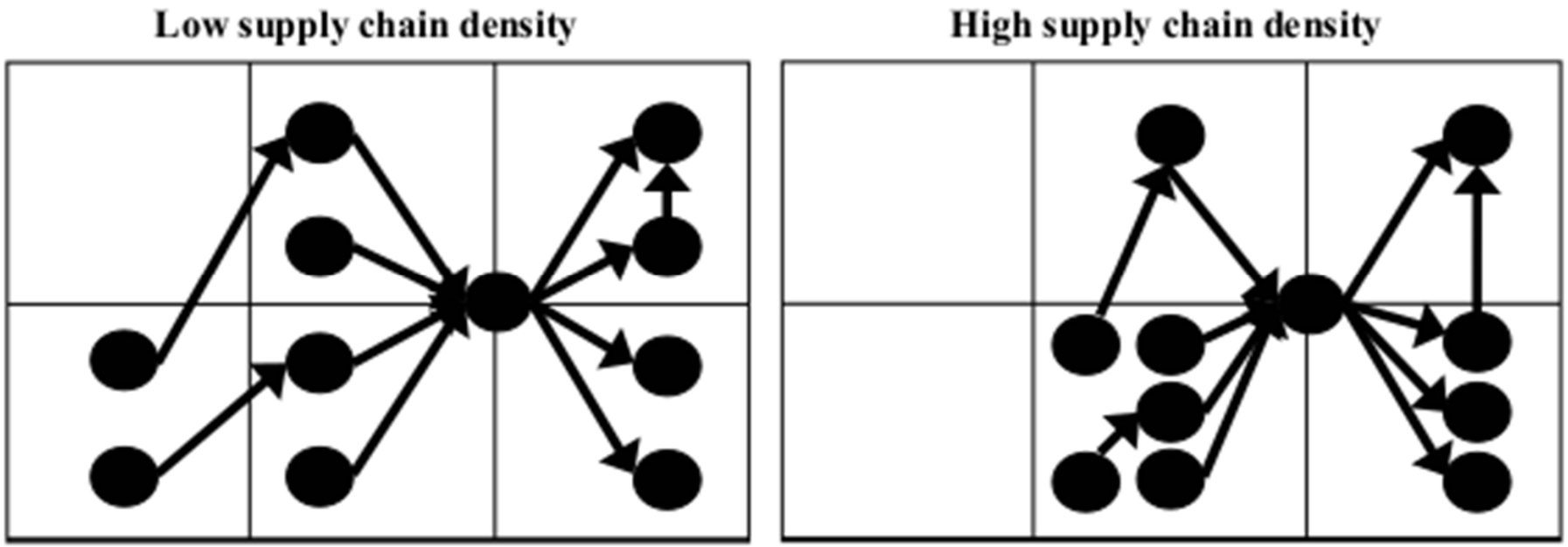
Higher complexity can mean: Processes are more complicated and therefore the supply chain risk is increased.
However: Higher complexity can also mean higher redundancy which can decrease the supply chain risk.





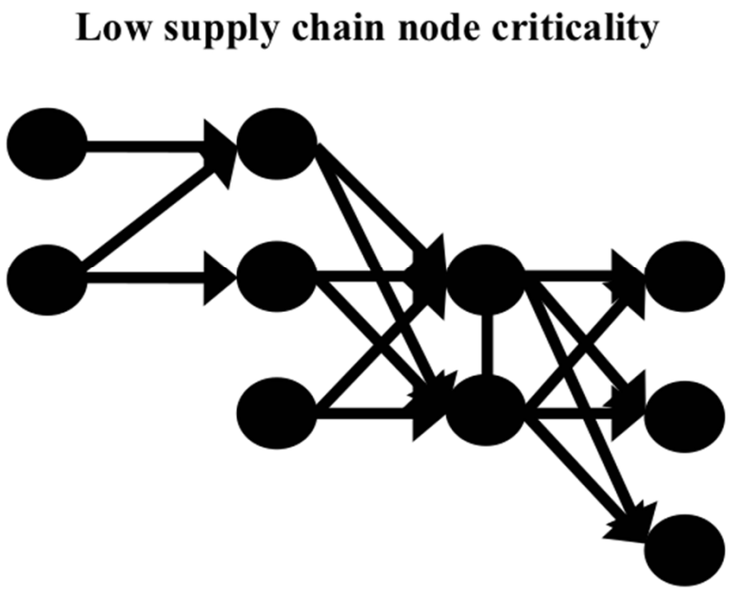
Density

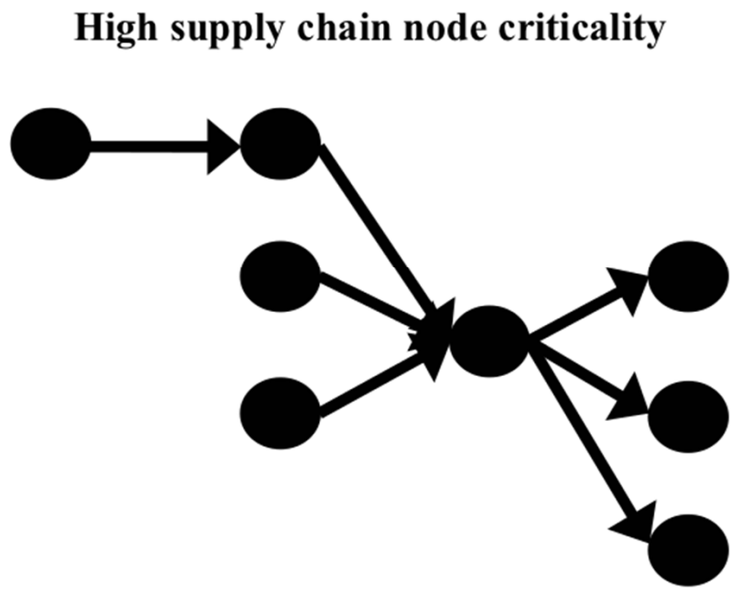
High Density: supplier nodes are located in the neighborhood (geographical or political). Higher Density usually means higher risk.



Critical node

Critical node: node that is important for the entire supply chain. Its dropout can lead to severe repercussions like missed demand and a non-delivery contract penalty.





Standard method to detect critical nodes: identify nodes with a high network centrality (e.g., betweenness, degree, or eigenvector centrality)

Proposed Method

- Determine critical nodes and links using robust optimization
- Regarding risks: Three kinds of optimization models
  - Deterministic optimization: no risk are considered, costs are minimized under several production, transportation and inventory constraints
  - Stochastic optimization: expected costs are minimized under several supply chain risk scenarios
  - Robust optimization: expected costs and cost variance are minimized, where the variance accounts for the uncertainty about the actual costs

Excurse: Connection Risk and Variance

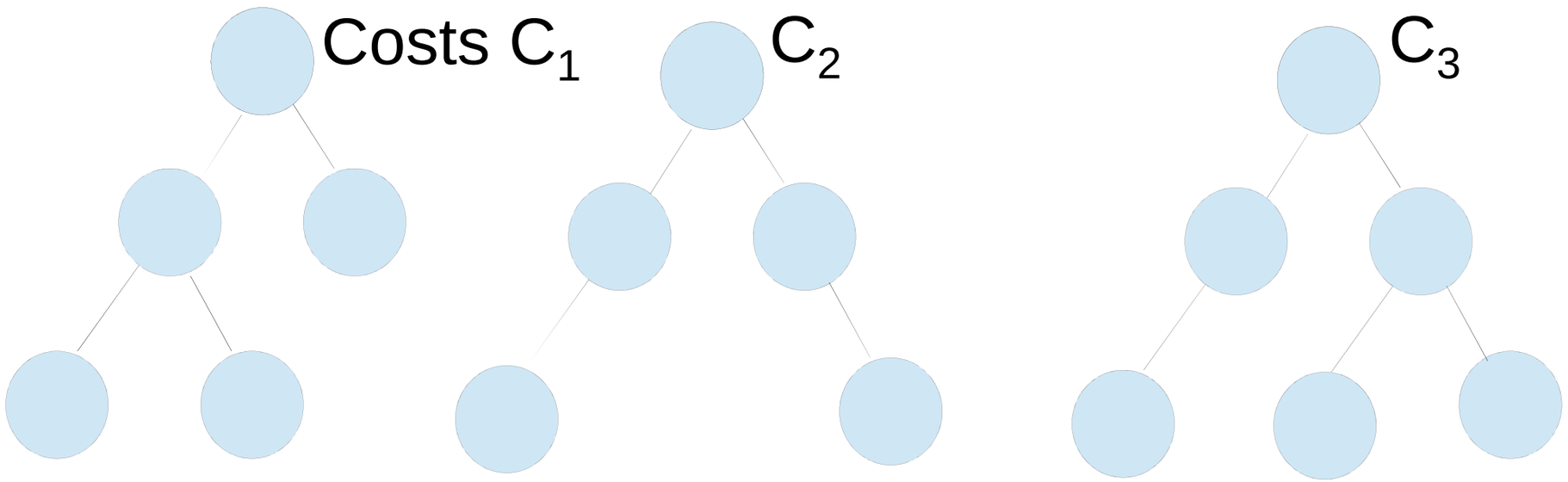
Example: two financial investments:

- Investment 1: guaranteed interest rate of 1% ⇾ variance of expected cash return is zero and the risk is very low.
- Investment 2: interest rate can assume every value between (-100% und 100%) ⇾ variance of expected cash return and risk of investment are both very high.
- Minimizing the variance means minimizing the risk

Stochastic optimization

Risk scenario 1 Risk scenario 2 Risk scenario 3

Costs C_1 C_2 C_3

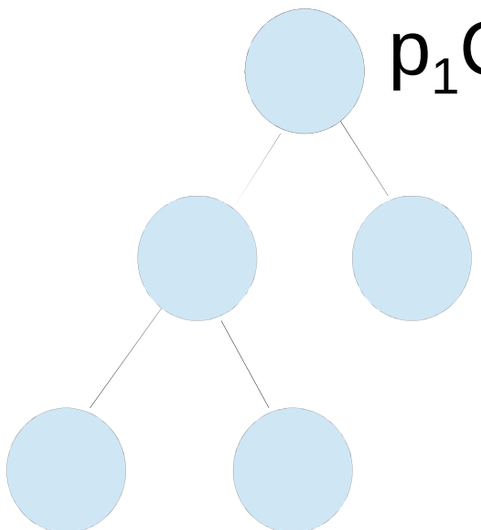


Stochastic optimization

p_i: probability that risk scenario i occurs

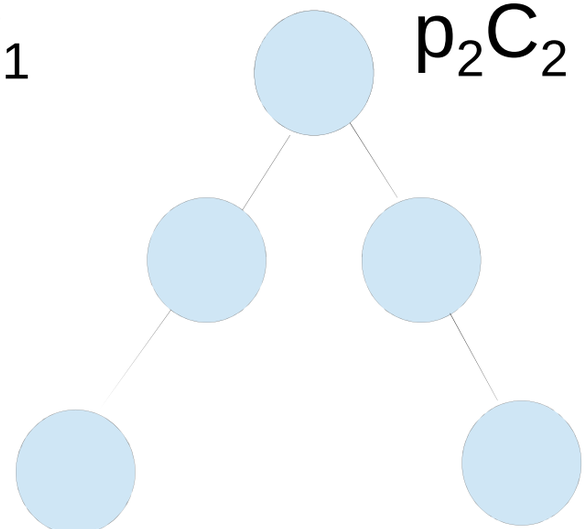
Risk scenario 1

p_1C_1



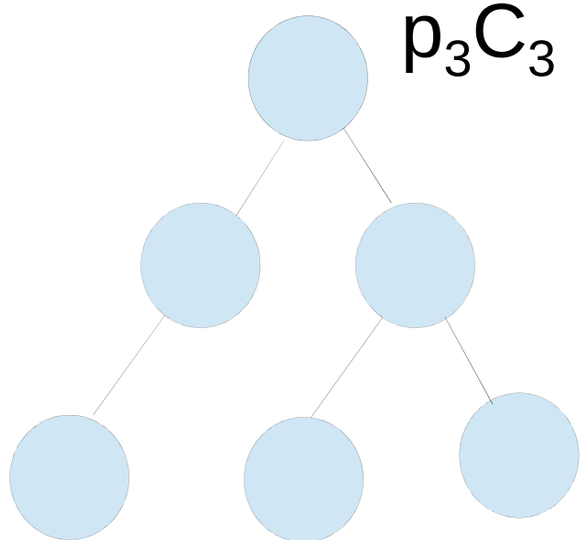
Risk scenario 2

p_2C_2



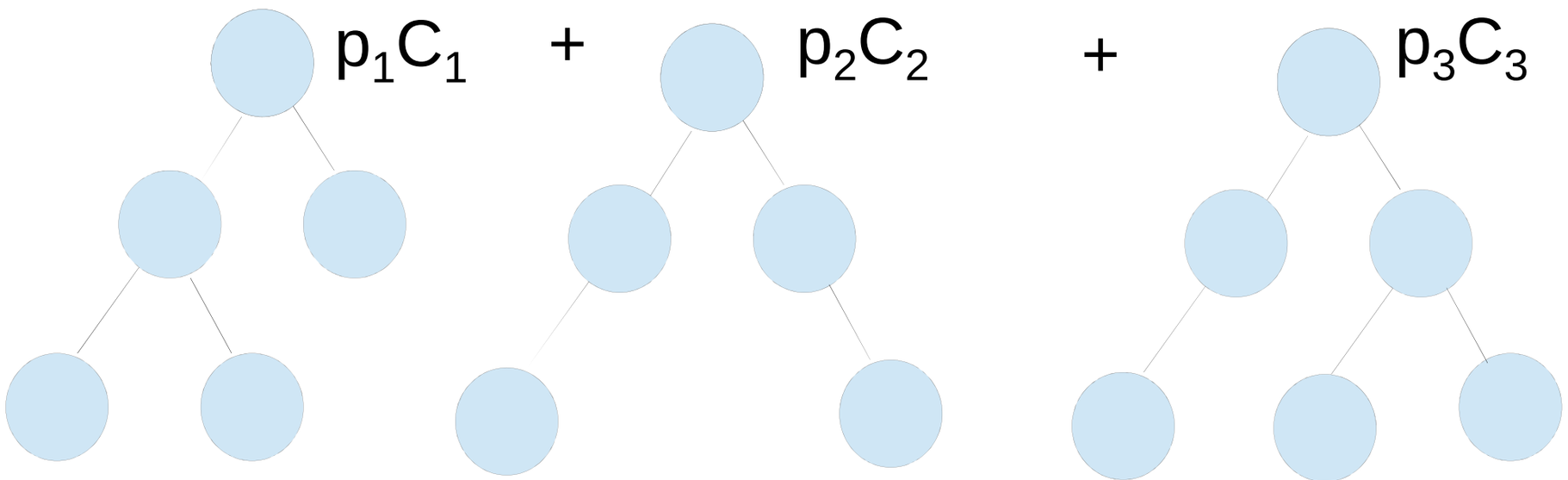
Risk scenario 3

p_3C_3



Stochastic optimization

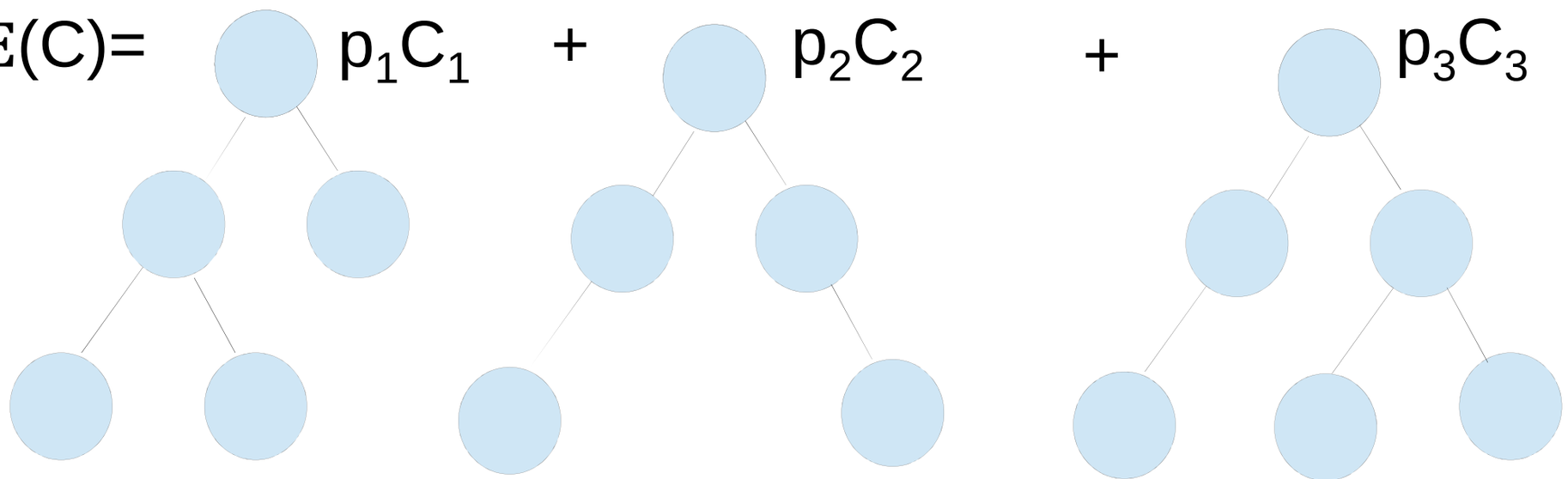
Risk scenario 1 p_1C_1 + Risk scenario 2 p_2C_2 + Risk scenario 3 p_3C_3



Stochastic optimization

Risk scenario 1 Risk scenario 2 Risk scenario 3

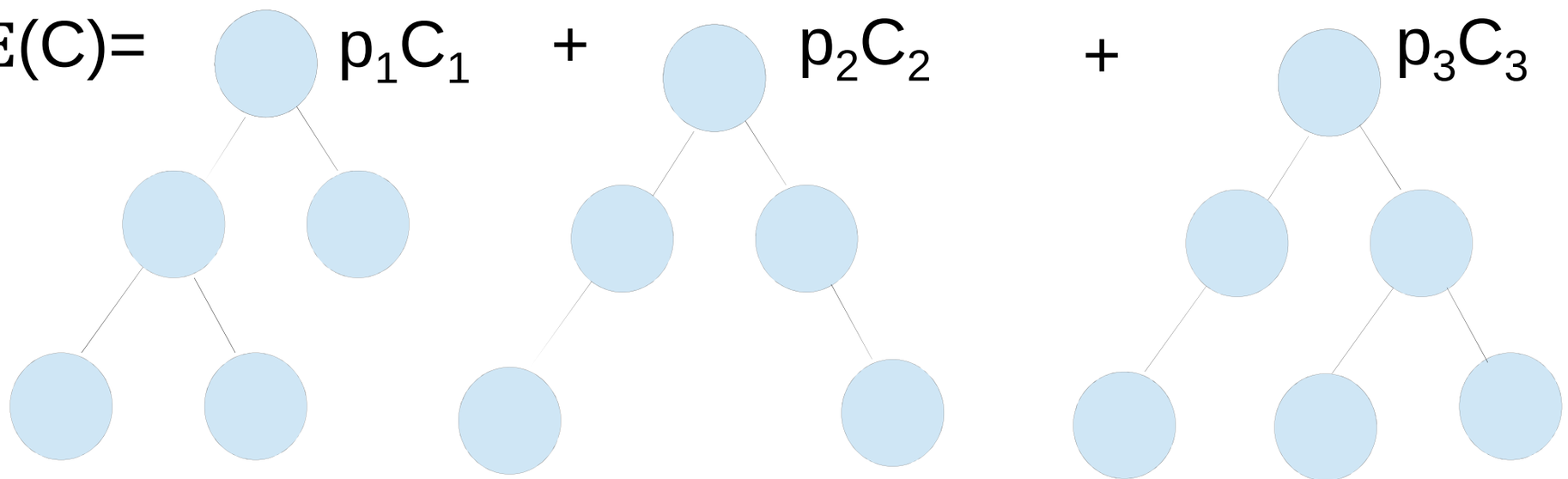
$\mathbb{E}(C) = p_1C_1 + p_2C_2 + p_3C_3$



Robust optimization

Risk scenario 1 Risk scenario 2 Risk scenario 3

$\mathbb{E}(C) = p_1C_1 + p_2C_2 + p_3C_3$

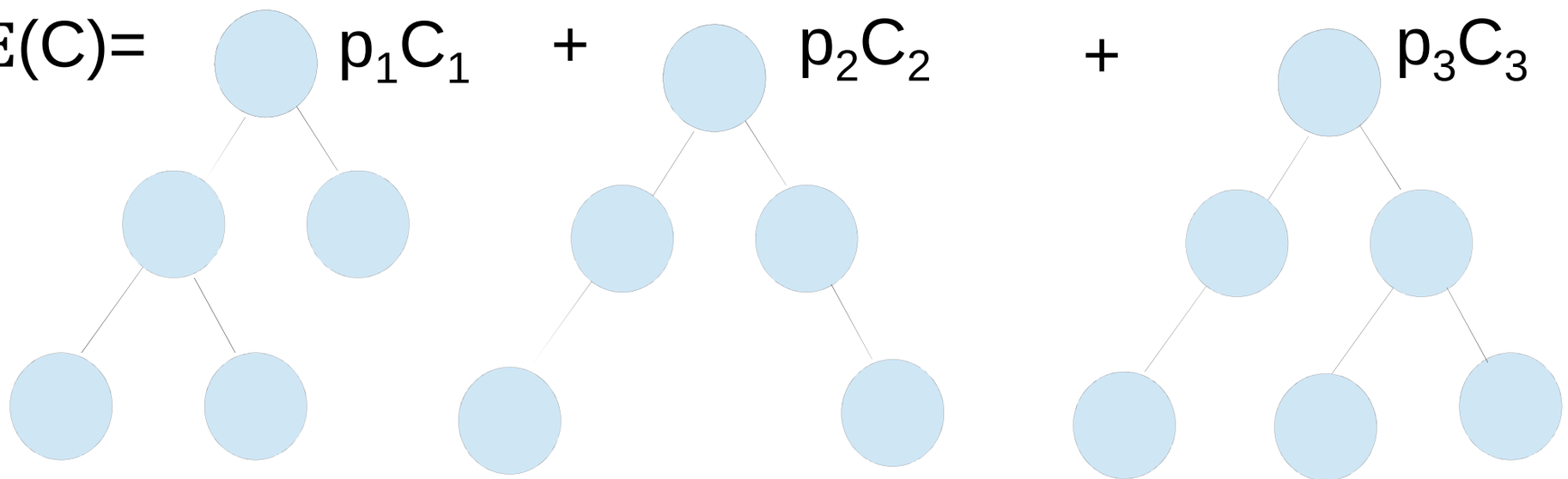


$\mathbb{V}(C) = \sum_s (p_s(\mathbb{E}(C) - C_s)^2)$

Robust optimization

Risk scenario 1 Risk scenario 2 Risk scenario 3

$\mathbb{E}(C) = p_1 C_1 + p_2 C_2 + p_3 C_3$



$\mathbb{V}_{abs}(C) = \sum_s p_s |(\mathbb{E}(C) - C_s)|$

Robust optimization

- Objective function: Min $\mathbb{E}(C)+\gamma\mathbb{V}_{abs}(C)$
- Costs include a penalty factor for unsatisfied demand: $\omega\sum_s p_s\alpha_k\delta_{ks}$
- δ_{ks} amount of unsatisfied demand
- $\sum_j\sum_n T_{jkns}+\delta_{ks}\geq d_{ks}$
- $d_{ks:}$ demand of customer zone k in scenario s
- T_{jkns}: quantity shipped from j to k by mode n in scenario s

Criticality of a node

- Remove this node from the supply chain
- Determine the new global risk costs using robust optimization
- Resulting increase of risk costs (expected costs + variance term) is indicator of node criticality
- Criticality of a transportation link can be estimated analogously

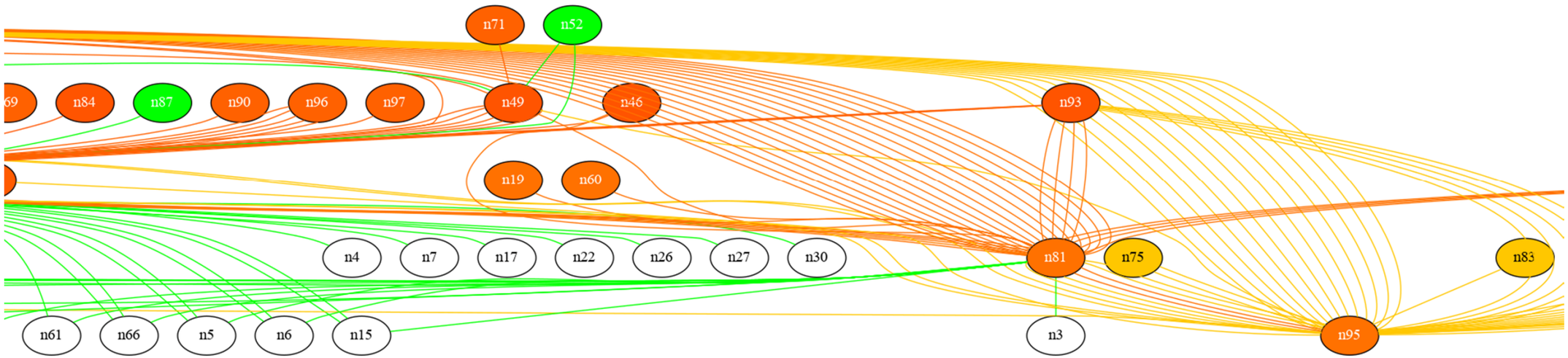
Dependency of critical nodes and links

- A link originating from a critical node can be uncritical or critical
- A link originating from a non-critical node is always uncritical

Current definition of criticality

- A node/link (colored green) is considered uncritical if risk costs are not increased
- A node/link is considered somewhat critical if risk costs are increased by X % (we use 30 %)
- A node/link is considered critical if risk costs are increased by at least Y % (we use 60%)
- Exact criticality threshold depends on degree of competition and corporate branch

Example

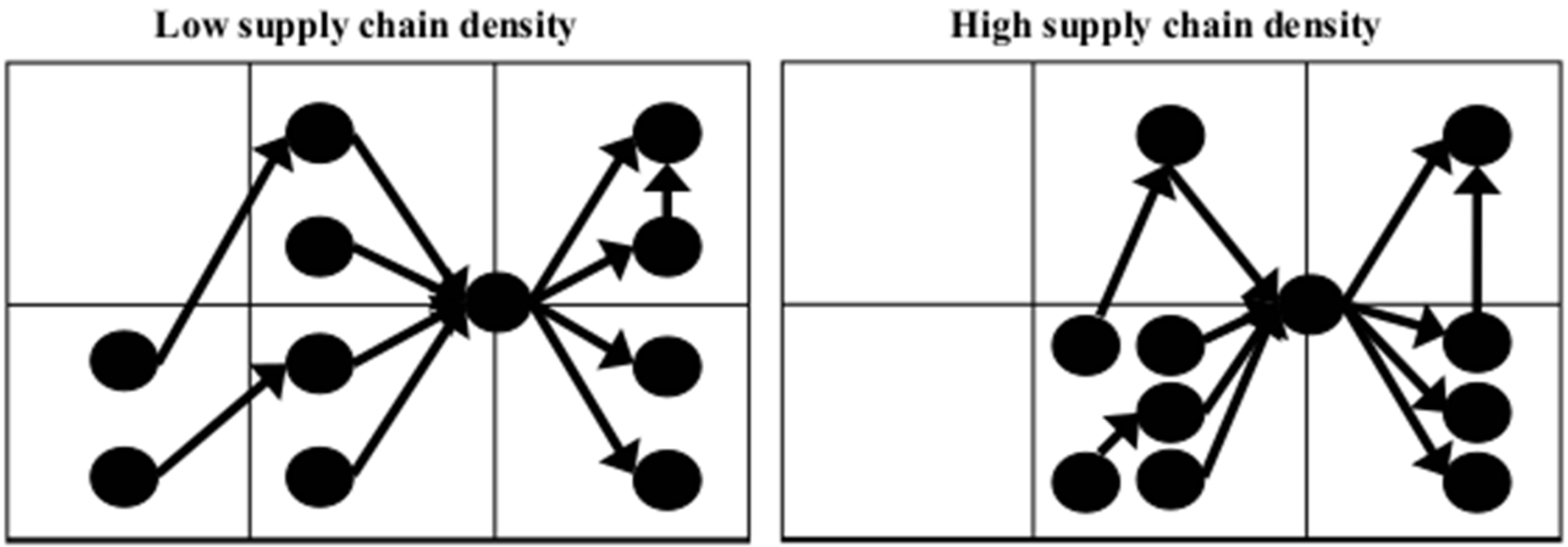


Links to the customers are uncritical
Links from suppliers are mostly critical
Most nodes are rather critical due to the lack of backup suppliers

Outlook into current research: Critical Groups

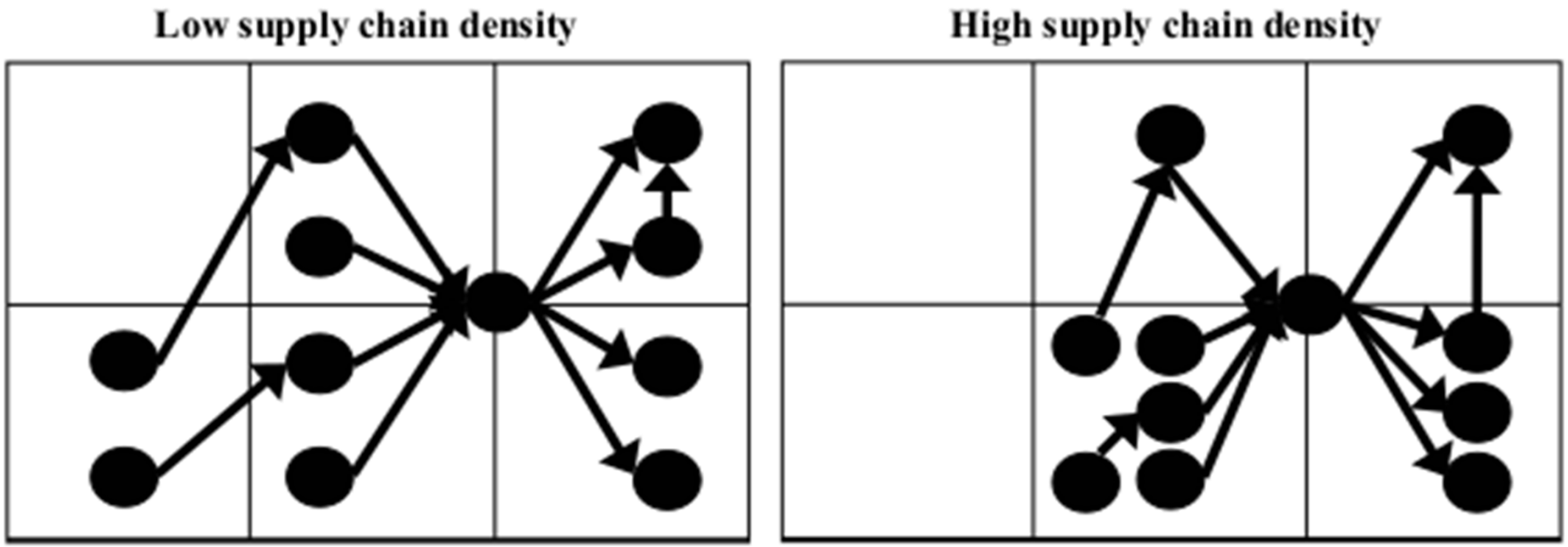
What about identification of supplier situations with high density. Does this method work there as well?

High Density: supplier nodes are located in the neighborhood (geographical or political). High Density can mean a high supply chain risk.



Critical Groups

High Density is not riskful per se. It constitutes a high risk, if there is a common risk trigger that endangers the suppliers.



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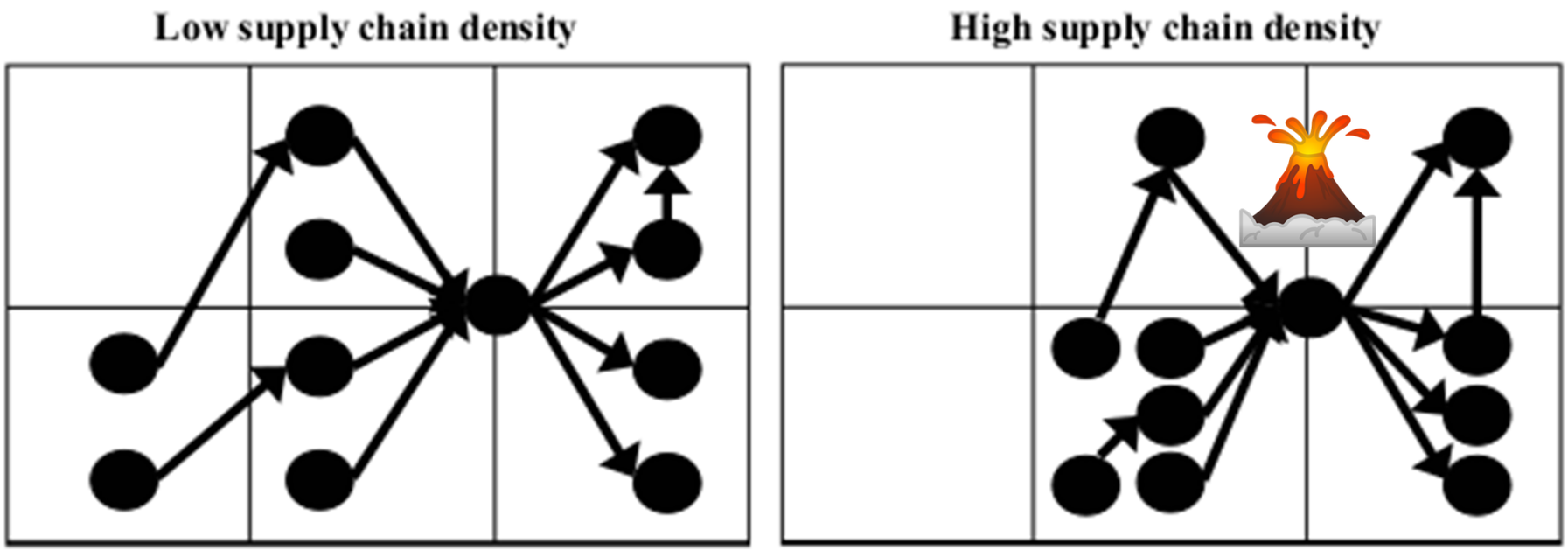
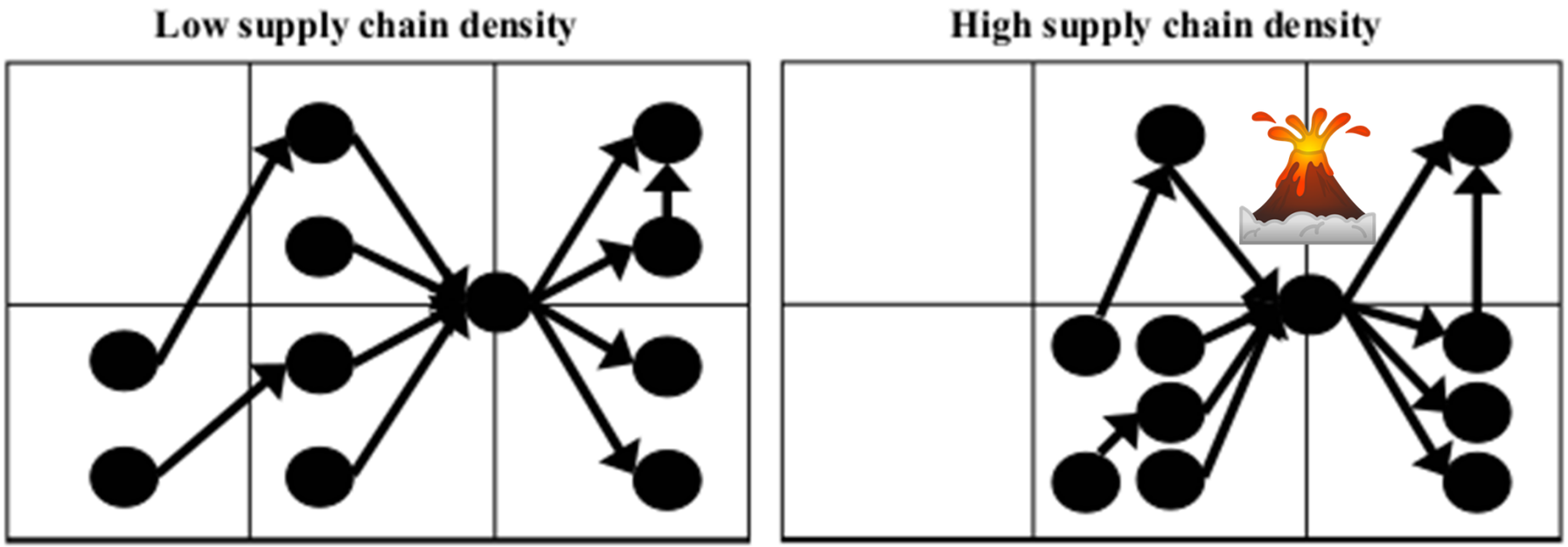


Critical Groups

We introduce the concept of a critical group.
Critical Group: group of suppliers affected by the same risk scenario whereas its complete failure has a high impact on the supply chain.



How to measure impact of group failure

- Same idea as for critical nodes and links
- Remove the whole supplier group from the supply chain, compute the new supply chain risk costs (excluding the group) and compare them with the old one (including the group).

Pro / Cons of our method in comparison with traditional graph-based approaches

- Exact cost estimate for criticality and density
- Costs estimate also considers supply chain risks and throughput of goods

- More effort to compute

Conclusion

- Methods were presented to assess group, node and link criticality by robust optimization
- In contrast to purely network based measures it provides precise risks estimates and takes risks into account
- We currently further investigate critical groups

Pictures

- Flame Picture: from www.freepik.com
- Motor engine Picture: from flaticon, https://www.flaticon.com/free-icons/sym-motor: Sym motor icons created by Icongeek26 – Flaticon
- Vulcano: https://cdn.icon-icons.com/icons2/1448/PNG/512/42463volcano_99098.png
- Lamborghini : https://www.nicepng.com/png/full/254-2547288_lamborghini-car-png.png
- Wheel: https://clipart-library.com/clip-art/57-578499_car-wheel-dhama-wheel-clipart-vector-clip-art.htm