Invited Talk

Lucerne University of Applied Sciences and Arts
HOCHSCHULE LUZERN

Robust Supply Chain Costs Minimization Considering Operational Risks

Invited Talk: NexTech 2020

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Invited Talk

- 2001: Diploma Degree at Saarland University
- 2001-2003: Scientific Assistant at the German Research Center for Artificial Intelligence (DFKI)
- 2003-2006: Scientist at the German Meteorological Service
- 2006-2010: PhD Student at the Distance University of Hagen
- 2011-2015: Postdoc at Goethe University Frankfurt am Main
- 2015-now: Research Associate at Lucerne University of Applied Science and Arts
- 2019-now: Lecturer at FFHS (Fernfachhochschule der Schweiz)

Supply Chain

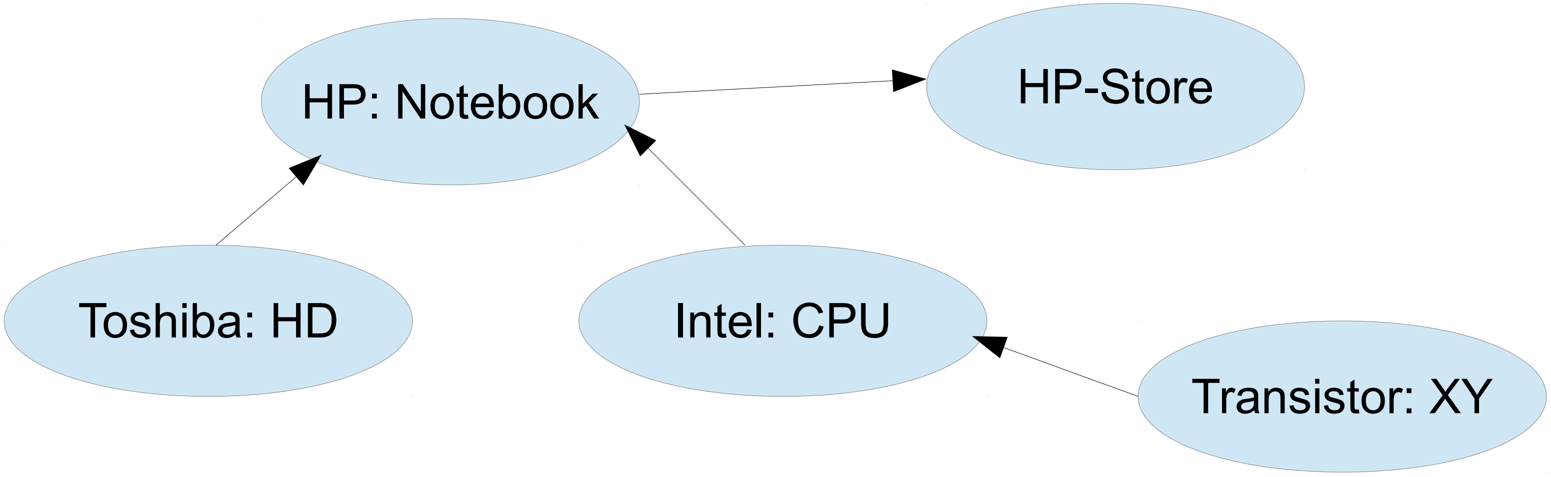
- Consider the production of a notebook
- To produce a notebook one needs
  - Hard drive
  - LCD
  - Keyboard
  - Touchpad …

To produce an LCD one need:

  - Rare Earth Materials
  - ….

Supply Chain

- A supply chain can be represented by a graph
- Nodes: locations / items
- Edges: transportation between locations



Costs minimization

Costs minimization can be accomplished using an optimization model:

Minimize $\Sigma_{iz} c_{iz} P_{iz} + \Sigma_{ijz} t_{ijz} Q_{ijz} + \Sigma_{iz} d_{iz} I_{iZ}$

- $D_{iz} \leq \Sigma_j \ Q_{j,i,z}$
- $Q_{j,i,z} \leq P_{jz} + I_{ji}$

…..

i,j : locations, z:item, $c_{iz/} d_{iz/} t_{ijz}$: production/inventory/transportationcosts

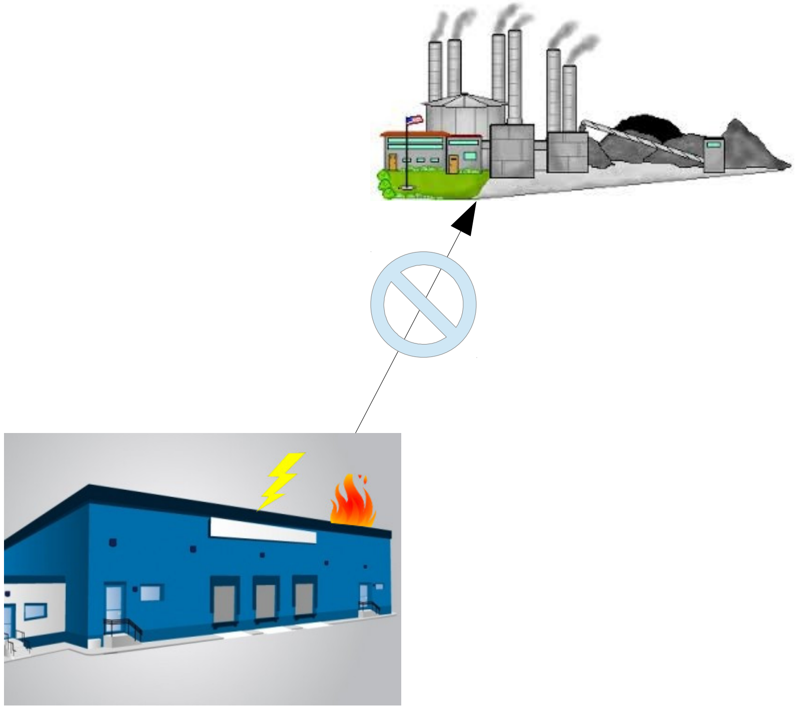
- D_{iz} : demand of item z at loction I
- P_{jz}: Number of items z produced at location j
- I_{ji} : number of items z contained in inventory at j
- $Q_{j,i,z}$: number of items z transported from i to j

Risks

A supply chain can be affected by several risks

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

Disruption risks



Possible disruption risks:

- Natural disaster
  - Fire, earth quake, lightning strike, volcano eruption
- Political risks
  - Labor strike, Brexit
- Sabotage
  - Cyber-attack, burglars

Group Risks

A certain risk event can cause a simultaneous breakdown of several suppliers

-Examples

- Strike: can affect several countries in the same country and industry branch
- Natural disaster: can cause a breakdown of all suppliers in a certain region

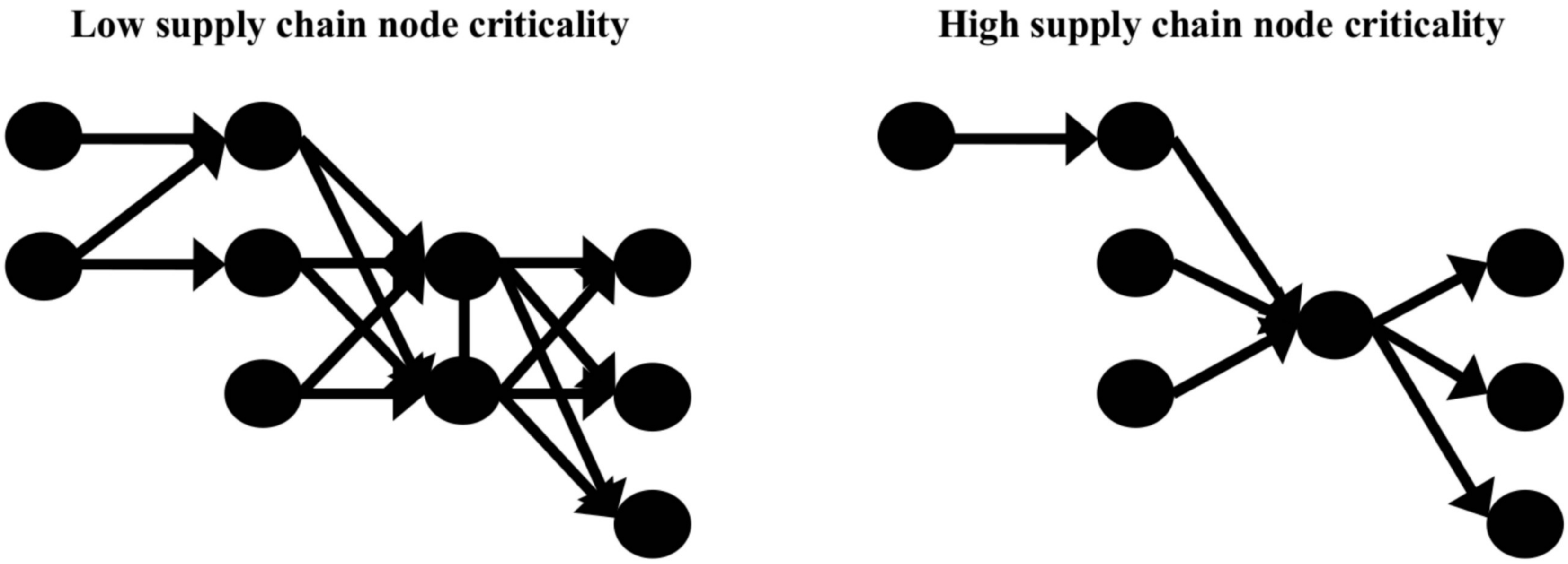
Topological Risk Measures

Principle:

Get rough overview over potential supply chain threats by looking at the supply chain structure or geographical map [2,3]

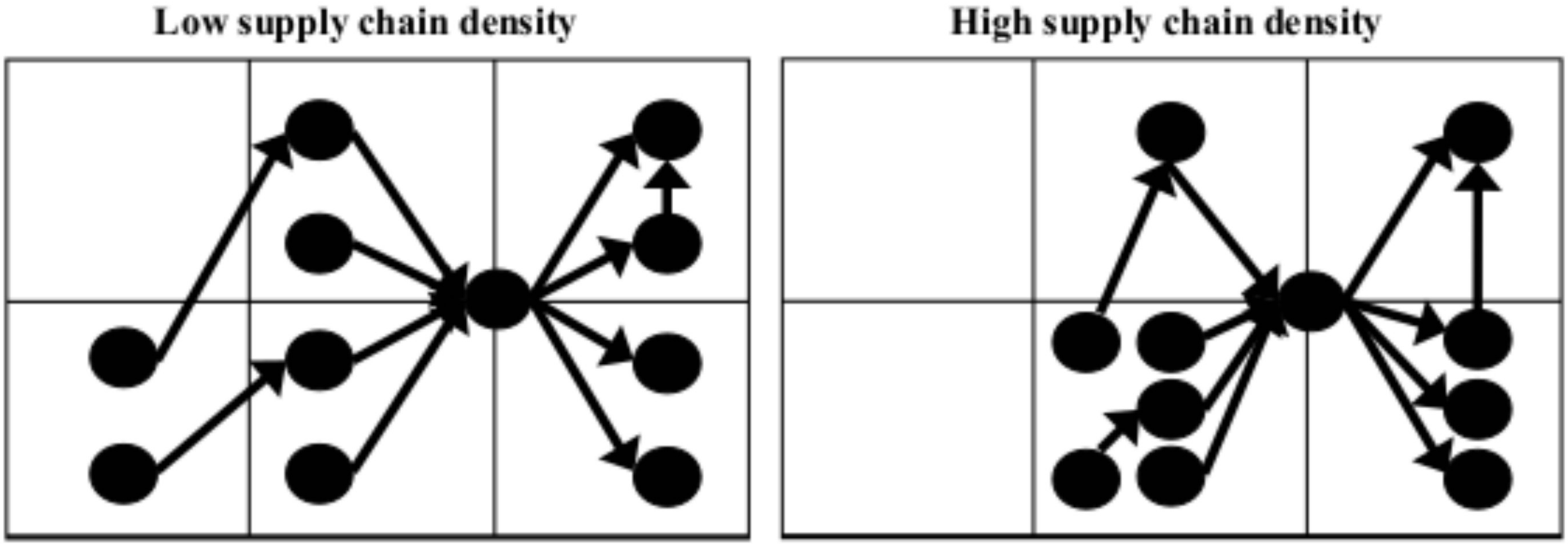
Topological Risk Measures

Critical notes[2,3]: Nodes that are essential for the proper functioning of the total supply chain



Topological Risk Measures

Density: Supply chain containing a geographical area with high number of suppliers might be vulnerable to group risks



Disruption risks

Topological risk measures only provide a rought overview over potential risks. Is there a more precise method?

Yes → using stochastic optimization

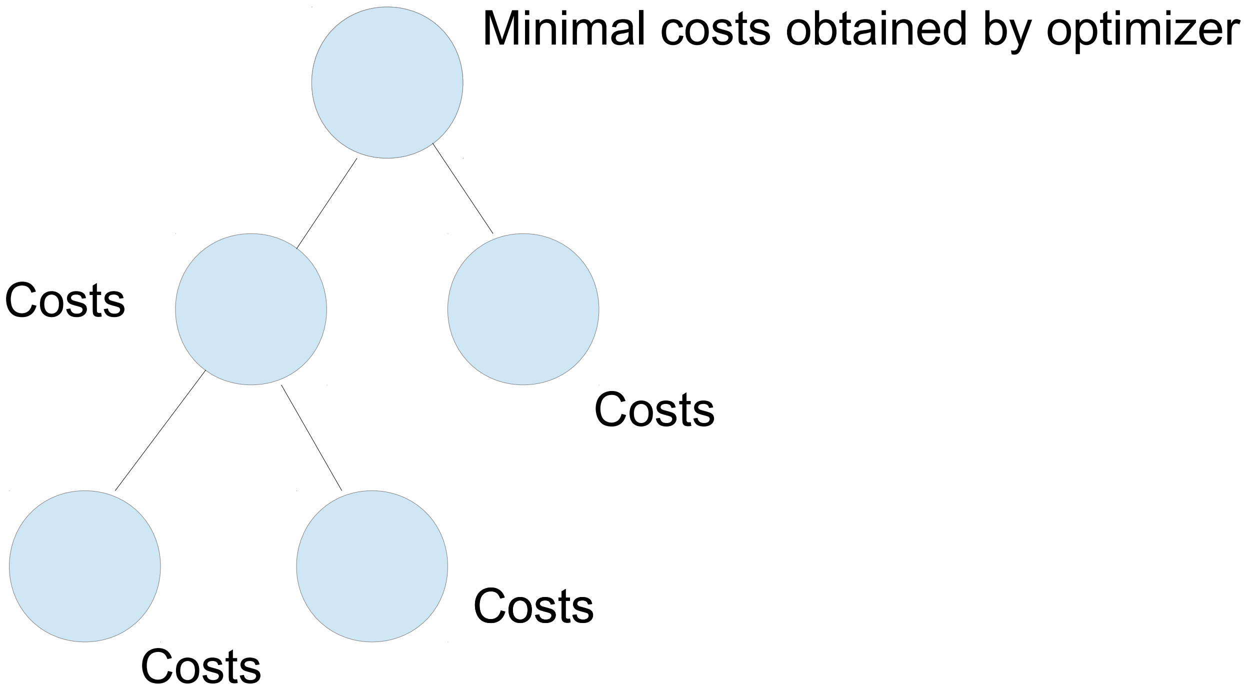
- Two possibilities to extend optimization model to consider disruption risks:
- Iterate first over risks and then over locations
- Iterate first over locations and then over risks

Research Questions

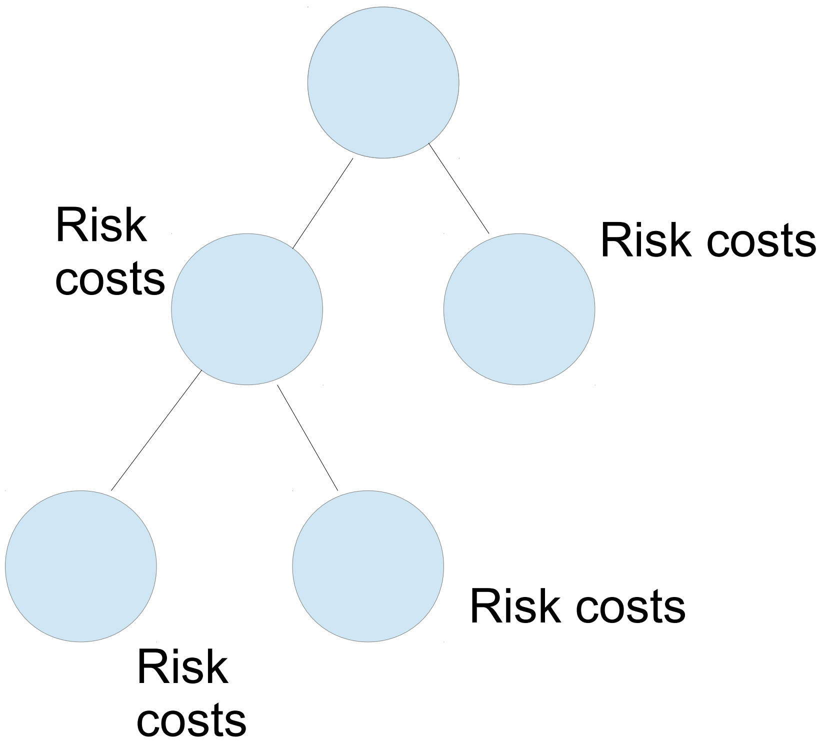
- What are the advantages and drawbacks of the two methods?
- What are advantages and drawbacks of automatic vs manual scenario generation?
- How large is the conducted error by assuming the scenarios are disjoint, while in reality they are stochastically independent?

Stochastic optimization

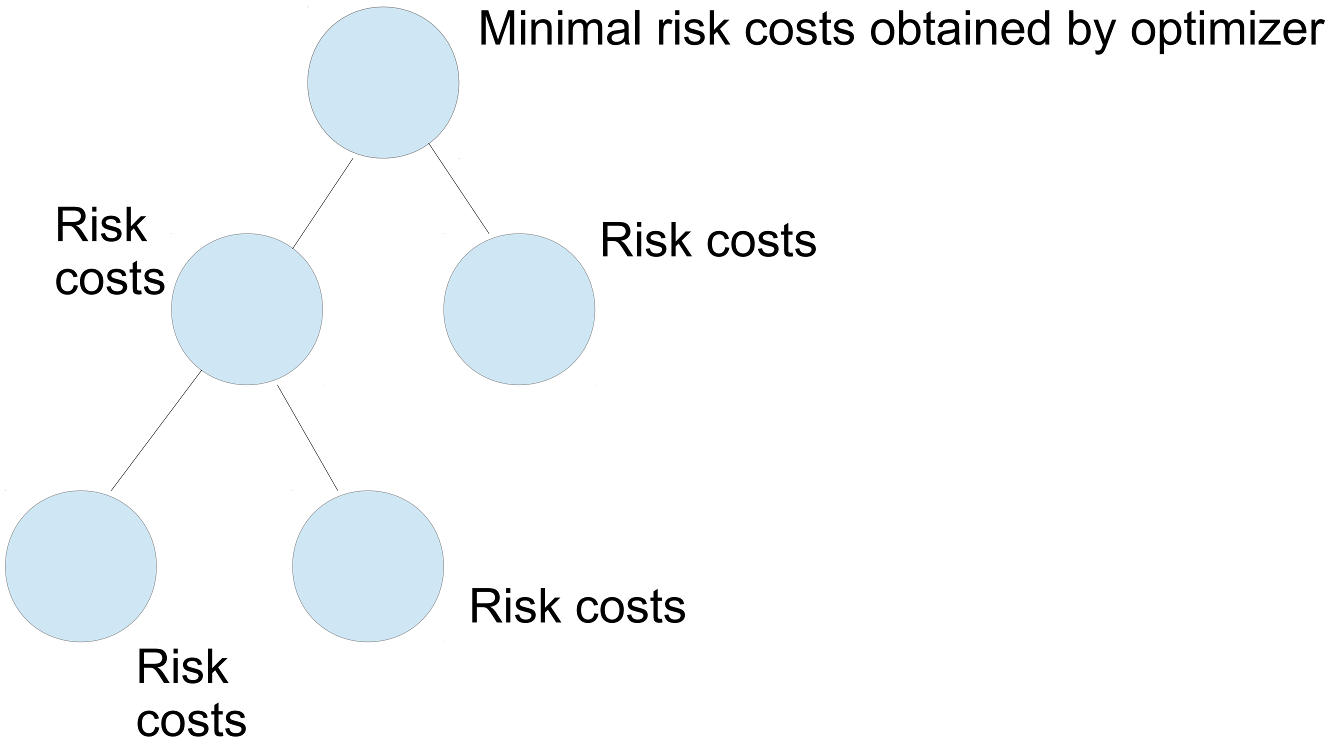
Possibility 1: Iterate first over risks and then over locations



Stochastic optimization



Stochastic optimization



Stochastic optimization

- A risk scenario is always associated to exactly one node in the supply chain
- A local estimation of risk costs is required

Stochastic optimization

- Fast, only one optimization run with only few decision variables
- As result: one single optimal supply chain flow

- Unclear, how to assess single and multiple source risks
- Unclear, how to deal with dependencies between risks and group risks

Stochastic optimization

So far:

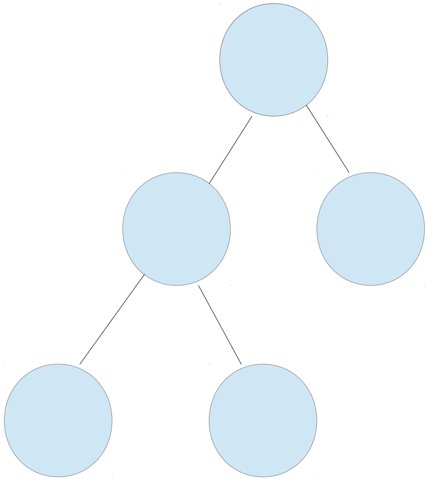
- Aggregate costs
  - Iterate over scenarios

Alternative model (Babazadeh and Razmi):

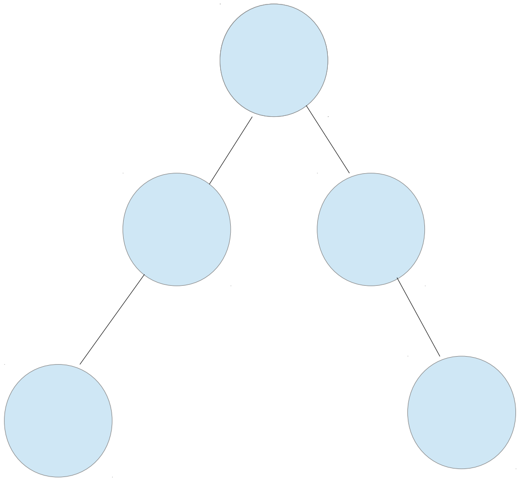
- Iterate over scenarios
  - Aggregate costs

Robust optimization [1]

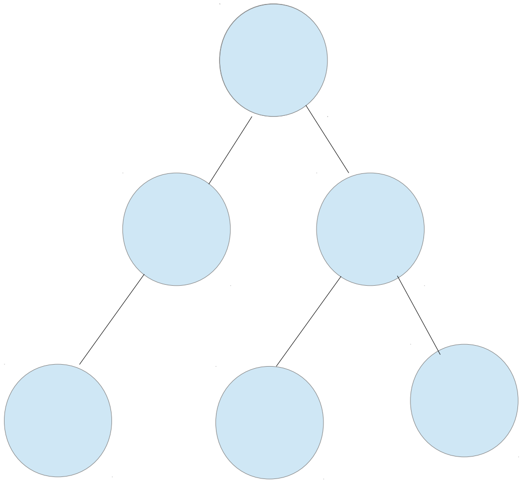
Risk scenario 1



Risk scenario 2

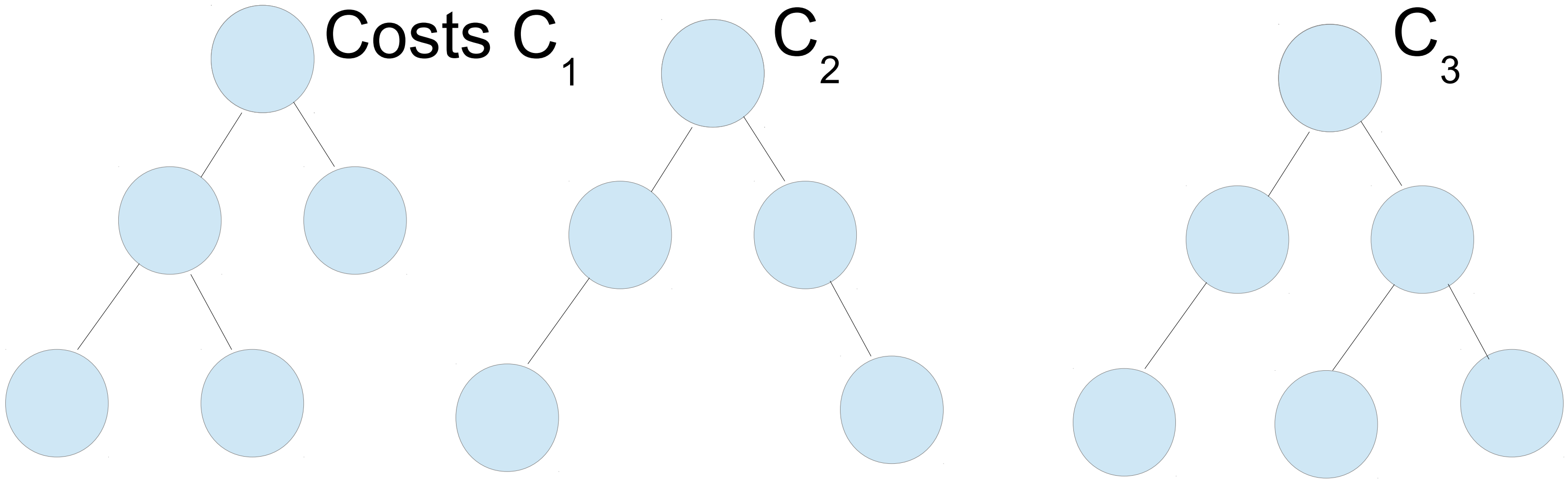


Risk scenario 3

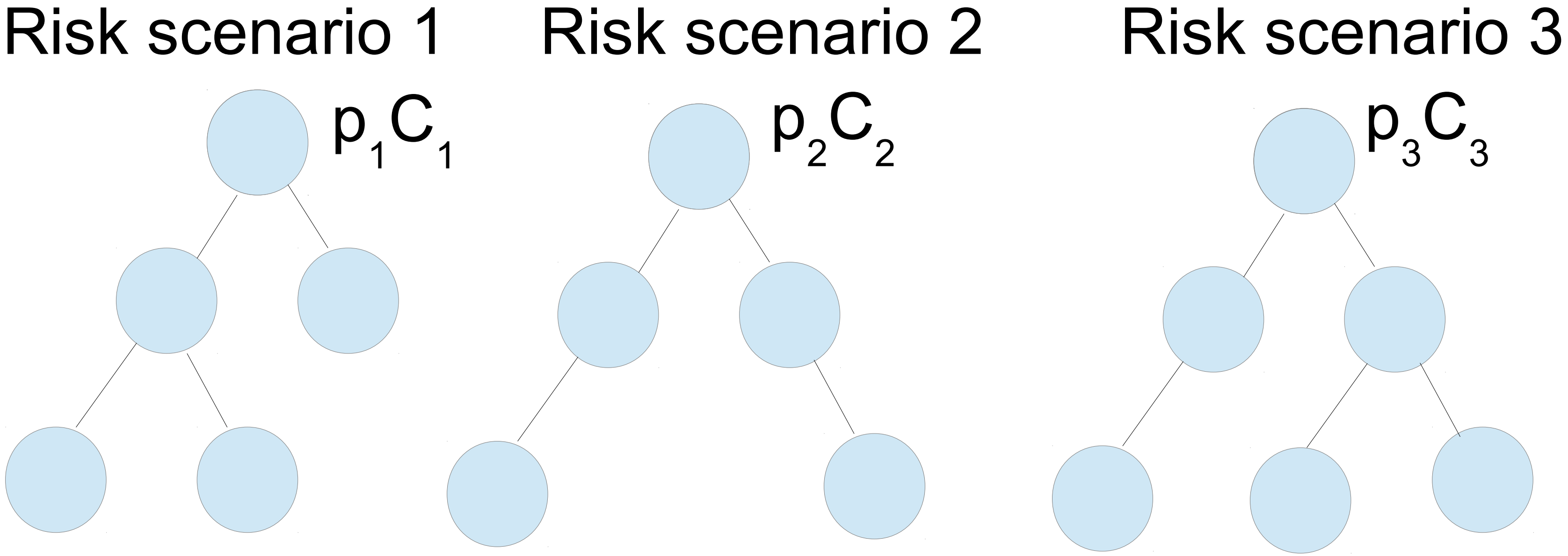


Robust optimization

Risk scenario 1 Risk scenario 2 Risk scenario 3



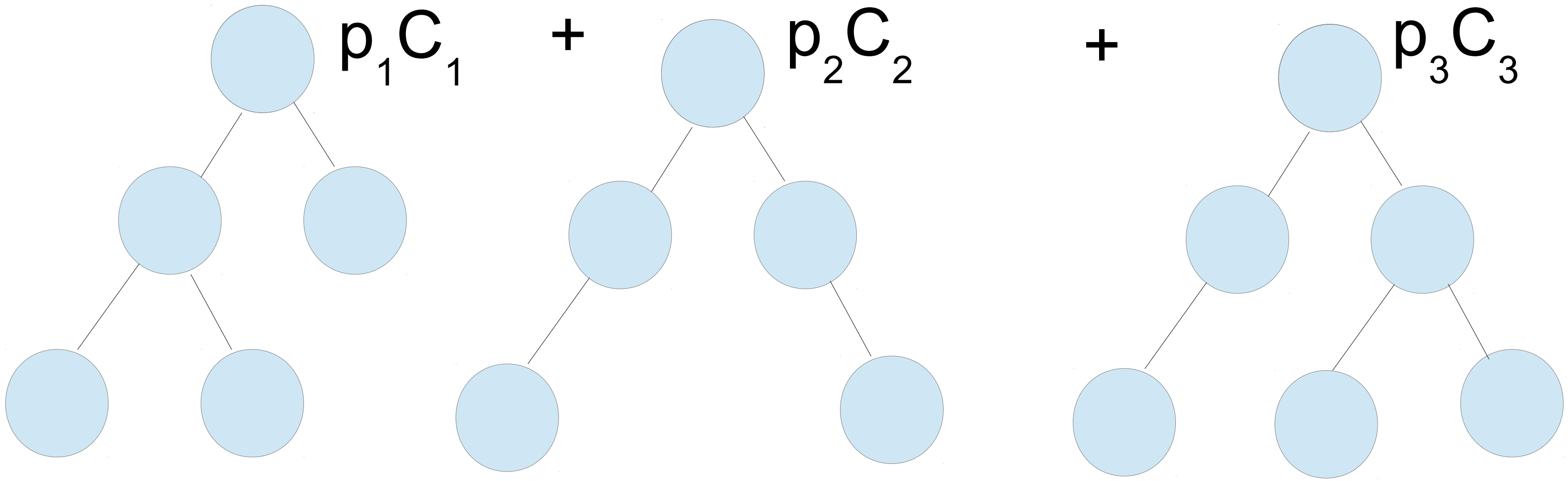
Robust optimization



Robust optimization

Risk scenario 1 Risk scenario 2 Risk scenario 3

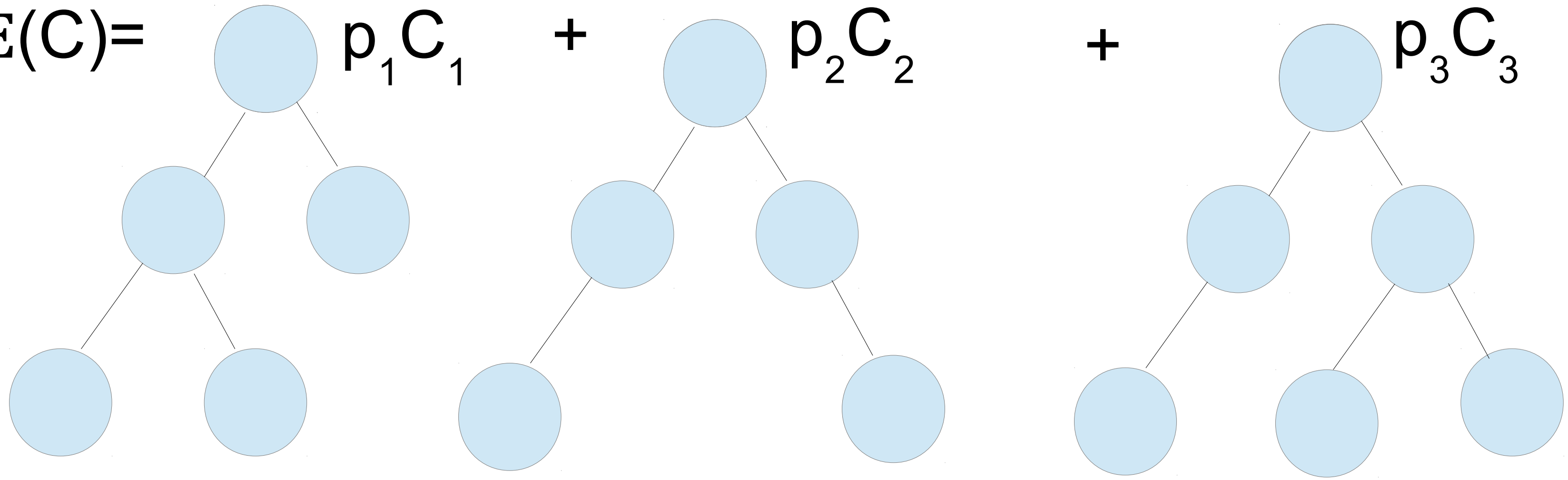
$p_1C_1 + p_2C_2 + p_3C_3$



Robust optimization

Risk scenario 1 Risk scenario 2 Risk scenario 3

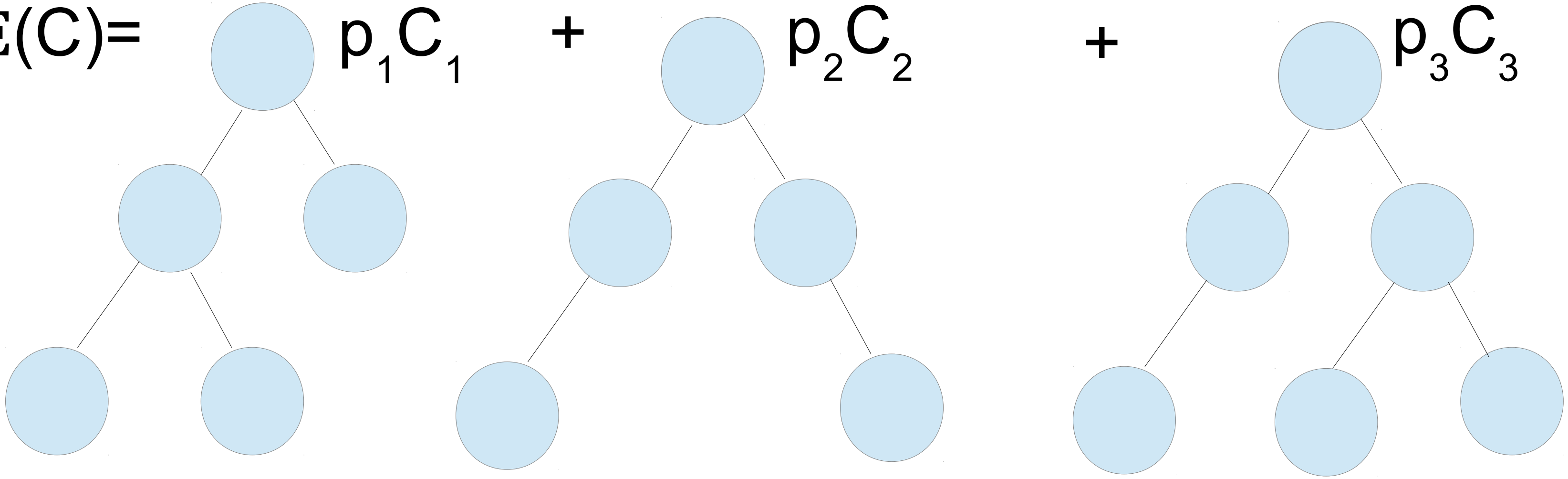
$$\mathbb{E}(C) = p_1 C_1 + p_2 C_2 + p_3 C_3$$



Robust optimization

Risk scenario 1 Risk scenario 2 Risk scenario 3

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

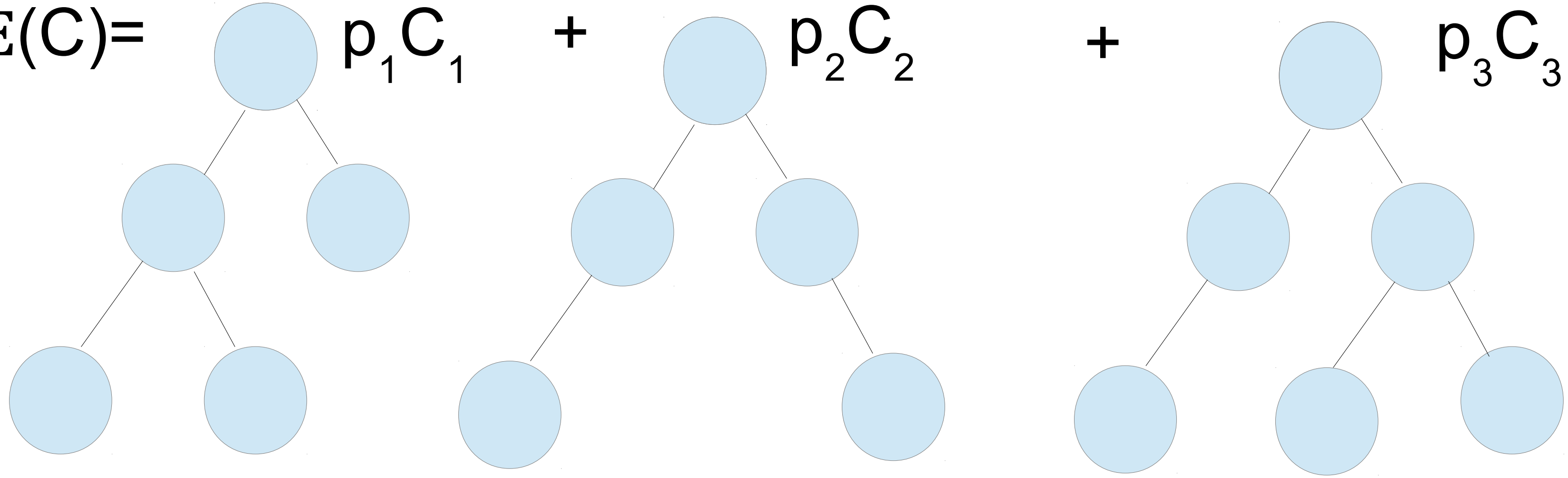


$\mathbb{V}(C)=\sum_s(p_s(\mathbb{E}(C)-C_s)^2)$

Robust optimization

Risk scenario 1 | Risk scenario 2 | Risk scenario 3

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

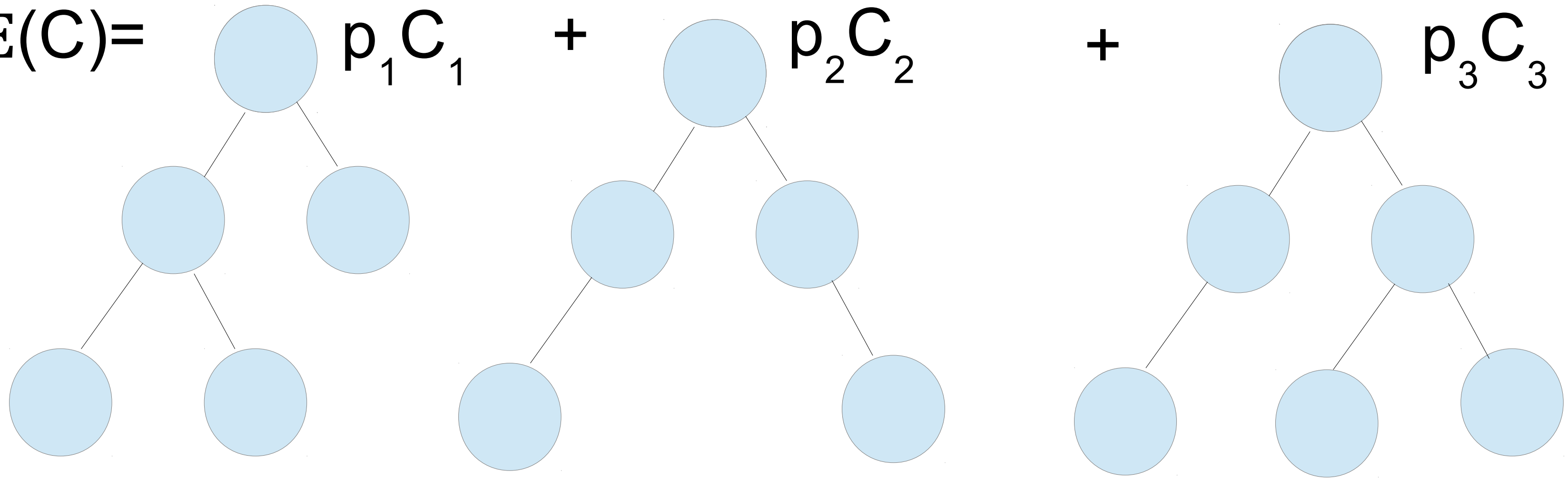


$\mathbb{V}_{abs}(C) = \sum_s p_s |(\mathbb{E}(C) - C_s)|$

Robust optimization

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:

obj:Min $\mathbb{E}(C)+\gamma\mathbb{V}_{abs}(C)+\omega\sum_s p_s\alpha_k\delta_{ks}$

δ_{ks} not satisfied demand

$\sum_j\sum_n Q_{jkns}+\delta_{ks}\geq d_{ks}$

$d_{ks:}$ demand of customer zone k in scenario s

Q_{jkns}: quantity shipped from j to k by mode n in scenario s

Robust optimization

- For each risk scenario, a separate minimal flow is determined by the optimizer
- Optimizer is only applied once

What is not provided by this method:

- An optimal overall flow

Terminology

- Without considering risks: Deterministic optimization
- Considering risks but no variance: Stochastic optimization

Considering risk and costs variance: Robust optimization

Questions

Do single source situations have a higher expected costs than dual source situations?

Yes, since single source situations lead more often to unsatisfied demands, which are penalized.

Pro / Cons

- Unsatisfied demand / group risks / single and multiple sourcing are treated properly
- Determines optimal flow for each risk scenario

- Rather slow caused by large amount of decision variables
- Determines no global overall optimal flow

Manager-defined scenarios

Supply chain expert specifies list of risk scenarios where each scenario contains of:

- probability of occurrence
- impact in form of supplier or transport disruption (example: production capacity is reduced by 80% due to this risk)

Automated scenario generation

Supply chain expert specifies list of risk scenarios templates where each scenario template contains

- probability of occurrence
- impact in form of supplier or transport disruption degree distribution (here Weibull) typically given by variance and expected value
- Scenarios are then sampled using this distribution

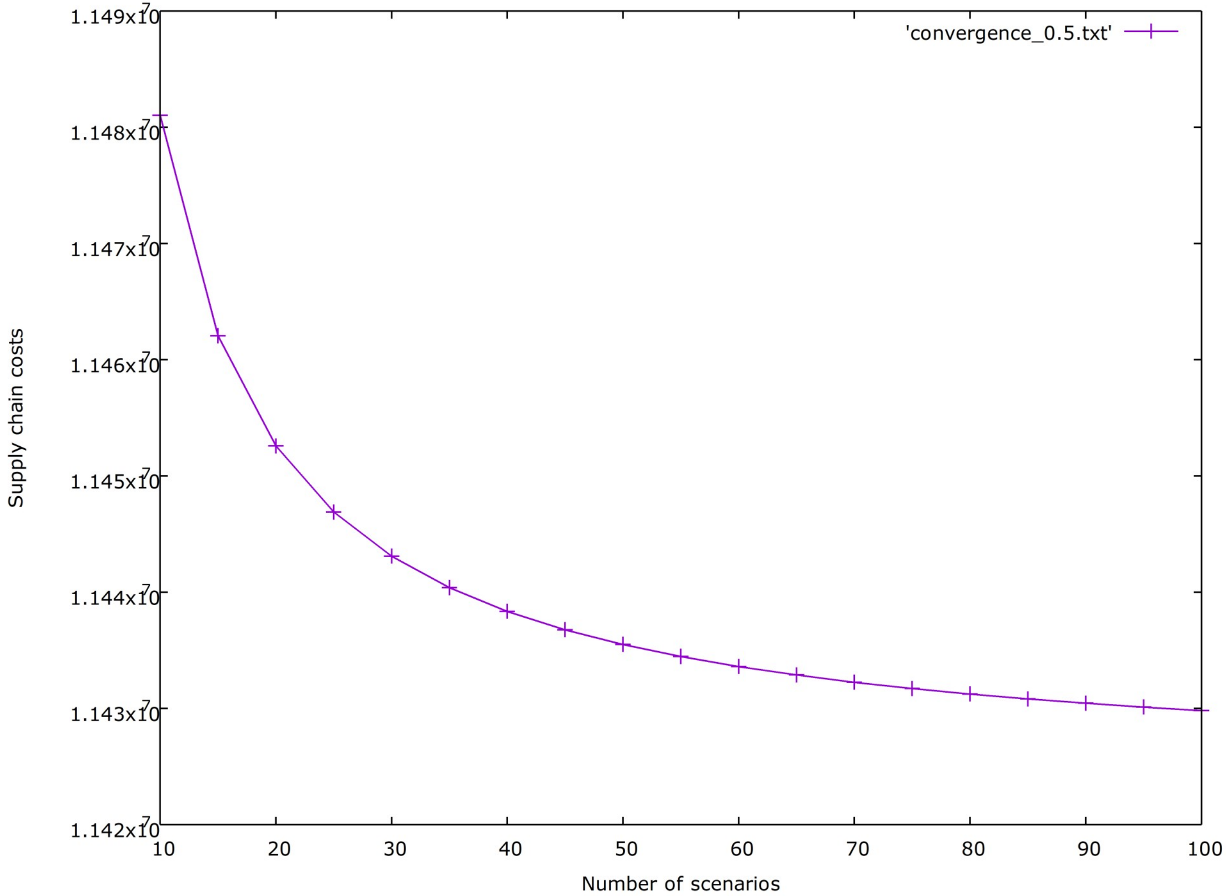
Research questions

- How many automatically generated scenarios are needed for a precise estimate?
- What is the critical point (point of convergence) using automatically generated scenarios?
- What is the convergence rate?
- (Future) What is the gain to use the full distribution in contrast to just use the expected value? For that we need a non-linear model.

Setup

We are using a real-world supply chain with:
-40 Customer
-100 suppliers
-230 Items
-200 transport links
So far we employed only stochastic and not robust optimization for the automated scenario generation approach.

Costs convergence



Findings

Findings:

- Manager defined approach can be seen as special case of automated scenario generation approach with scenarios $\rightarrow \infty$ and variance $\rightarrow 0$
- so, costs obtained for manager-defined scenarios be seen as approximately the convergence point for the automated approach with small variance (here 0.05)
- with 100 scenarios, we still have an estimated error of 0.05 %
- converge rate: only sublinear, i.e. rather slow convergence

Error Estimation

- For the robust/stochastic optimization approach it is assumed that the risk scenarios are all disjoint:
- However in practice they are more likely to be independent.
- This can cause the sum of the probabilities to be too large, in extreme cases even exceed one.
- How much can the sum of probabilities deviate from the correct value?
- We can estimate this error using the formula of Sylvester.

Error Estimation

$Error=(\sum_{i=1}^{n} P(S_i)-\sum_{k=1}^{n} (-1)^{k-1}\sum_{1\leq i1<...<ik\leq n} P(S_1\cap \ldots P(S_n))$

$=(\sum_{i=1}^{n} P(S_i)-\sum_{k=1}^{n} (-1)^{k}\sum_{1\leq i1<...<ik\leq n} P(S_1)...P(S_n))$

S_i: risk scenario I

$P(S_i)$: probability of risk scenario i

In our setup:

Absolute error: 0.0001

Relative error: 0.0067

Conclusion

- Robust optimization is a powerful approach for dealing with supply chain risks
- It allows for considering partial breakdowns as well as group risks
- The number of automatically generated scenarios required for reliable cost estimates in our example setup is >100 and the costs converges only sublinear
- Performance of single period robust optimization model is high for our example setup with 8 scenarios (only several seconds)

Future Work

- Use automatic scenario generation together with nonlinear models (for instance: models containing integer constraints) and robust optimization (currently only stochastic optimization)
- Use of a multiperiod robust optimization model
- Combining topological risk models with a robust optimization model

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- [1] Reza Babazadeh and Jafar Razmi. A robust stochastic programming approach for agile and responsive logistics under operational and disruption risks. International Journal of Logistics Systems and Management, 2012.
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- [3] Mauro Falasca, Christopher W. Zobel, and Deborah Cook. A decision support framework to assess supply chain resilience. In Proceedings of the 5th International ISCRAM Conference, Washingon, DC, 2008.
- [4] Mark Treleven, Sharon Bergman, and Schweikhart. A risk/benefit analysis of sourcing strategies: Single vs. multiple sourcing. Journal of Operations Management, 7(4), 1988.