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FLEXIBLE SUPPLY CHAIN PLANNING FOR STOCHASTIC CATASTROPHIC ENVIRONMENTS

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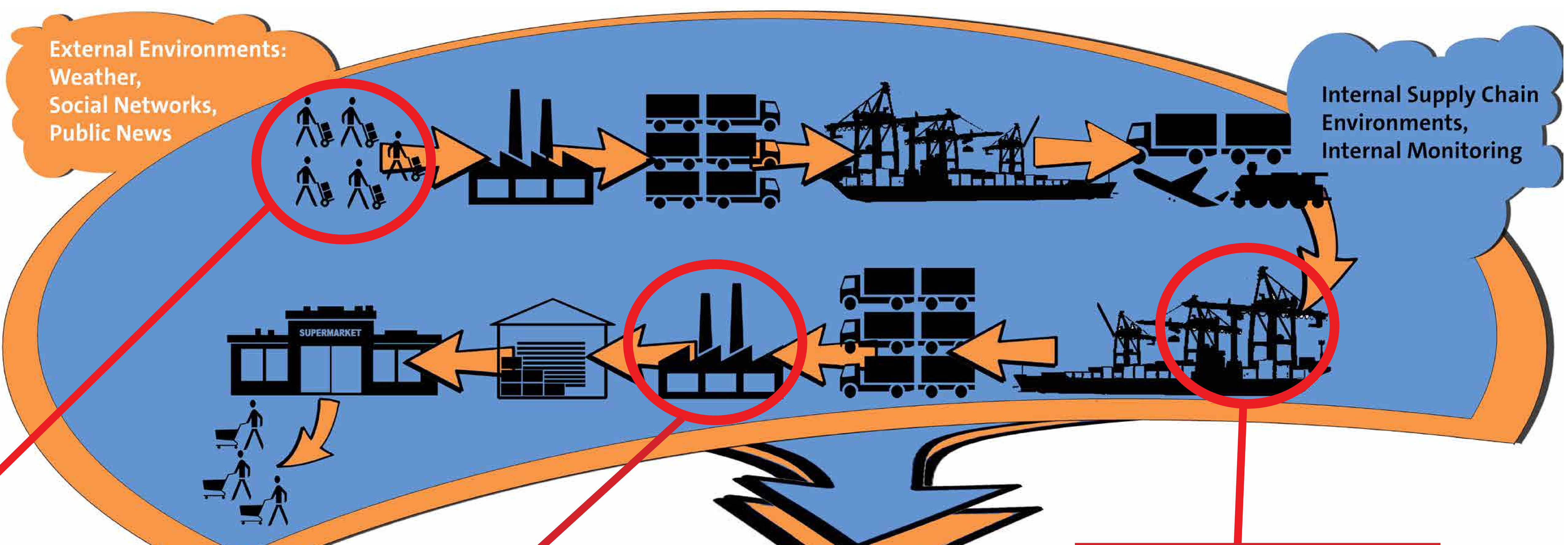
Flexible supply chain planning is an efficient way to cope with **future uncertainties**. Our focus lies on **low-frequency** and **high-impact supply chain risks**. Future potential catastrophic disruptions are forecasted based on **Supply Chain internal** and **external Big Data analyses**. Uncertainties are modeled by a **multi-stage scenario tree**. An objective function and constraints are defined in a **scenario-based multi-stage stochastic programming model**. After creating the scenario tree and the stochastic programming model, a set of **high-quality feasible solutions** (purchasing plan, production plan, transportation plan, distribution plan, etc. which merge into a supply chain plan) are generated by **PYOMO**. The **supply chain plan** is adopted into practice on a **rolling horizon**. **Re-planning** becomes necessary once **new information** is available.

Assuming possible Disruptions in a Global Supply Chain



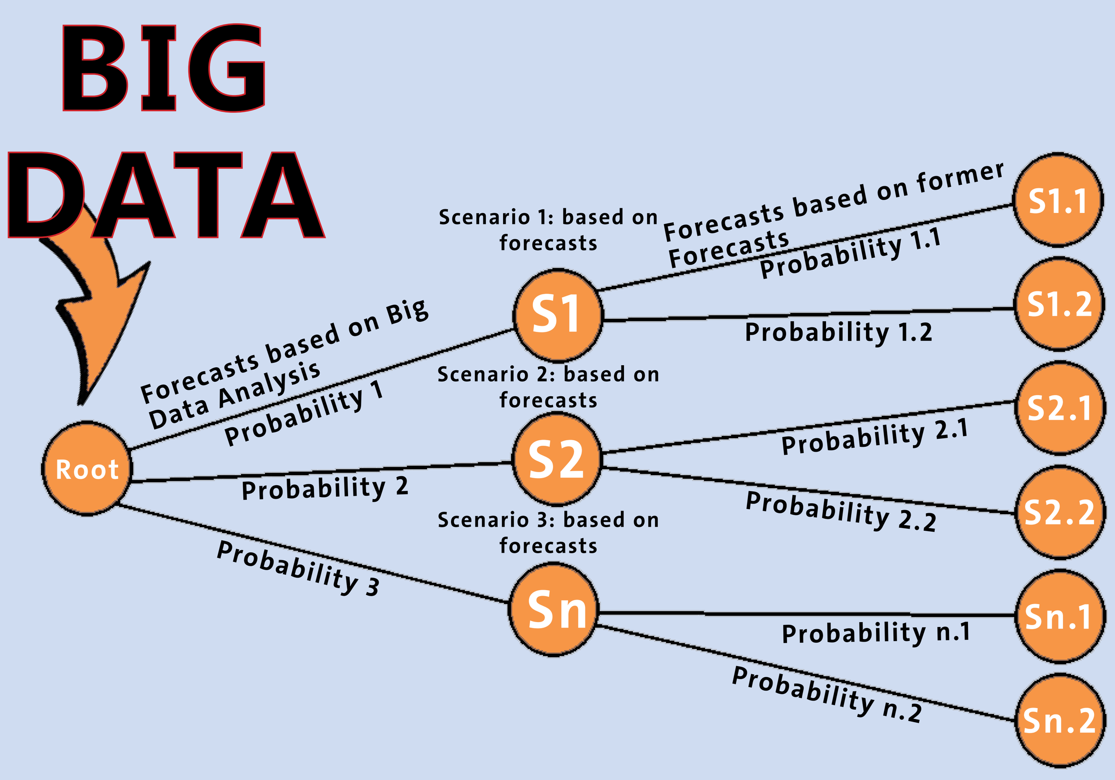
BIG DATA

Assumption 1: In Country A a coup d'état and its subsequent civil war might lead to a breakdown in all economic activities.

Assumption 2: Due to an earthquake all production facilities in Country B might be destroyed. The Infrastructure might also be broken down.

Assumption 3: At the most important port of Country C a huge explosion might destroy large parts of all facilities. Goods, containers and also ships are concerned.

Scenario Tree



Based on forecasting of potential catastrophic disruptions, a scenario tree is used to show possible realizations of the future. Each root-leaf-path defines a scenario, which represents one possible realization. An initial decision has to be made at the root-node. Further decisions are made at other non-leaf nodes stage by stage by considering future uncertainties.

Stochastic Programming

Objective Function:

$$\min\left\{TC^{1st} + \sum_{s\in S} P_s \cdot TC_s^{2nd}\right\} \quad (1)$$

1st Stage Costs:

$$TC^{1st} := \sum_{T_0\le t<T_0+T_{1st}} C_t^{SC} \quad (2)$$

2nd Stage Costs (for each scenario s ∈ S):

$$TC_s^{2nd} := \sum_{T_0+T_{1st}\le t\le T_f} C_t^{SC} \quad (3)$$

Decision Variables:

1st stage variables: $T_0 \le t < T_0 + T_{1st}$
2nd stage variables: $T_0 + T_{1st} \le t \le T_f$

Q_{tpi}^{Purc}: Purchasing quantity of material $p \in P^{Material}$ at node $i \in N^{Asm} \cup N^{Pro}$ at time $t \in T$

Q_{tp}^{Proc}: Processing quantity of component $p \in P^{Core}$ at the processing center $n \in N^{Pro}$ at time $t \in T$

Q_{tpi}^{Asm}: Assembling quantity of the final product $p \in P^{Final}$ at assembling center $i \in N^{Asm}$ at time $t \in T$

Q_{tpijm}^{Inter}: Transportation quantity of product $p \in P$ on international transportation link $(i,j) \in Conn^{Inter}$ launched at time $t \in T$ with transportation mode $m \in M$

Q_{tpij}^{Inland}: Transportation quantity of product $p \in P$ on inland transportation link $(i,j) \in Conn^{Inland}$ launched at time $t \in T$

Supply Chain Cost Functions:

$C_t^{SC} := \sum_{i\in N^{Pro}\cup N^{Asm}} \sum_{p\in P^{Material}} C_{pi}^{Purc} \cdot Q_{tpi}^{Purc}$ (materials purchasing cost)
$+ \sum_{(i,j)\in Conn^{Inter}} \sum_{p\in P^{Core}\cup P^{Final}} \sum_{m\in M} C_{pijm}^{Inter} \cdot Q_{tpijm}^{Inter}$ (international trans cost)
$+ \sum_{(i,j)\in Conn^{Inland}} \sum_{p\in P} C_{pij}^{Inland} \cdot Q_{tpij}^{Inland}$ (inland trans cost)
$+ \sum_{i\in N^{Pro}} \sum_{p\in P_i^{Node}} C_i^{O} \cdot Q_{tp}^{Proc}$ (processing cost)
$+ \sum_{i\in N^{Asm}} \sum_{p\in P_i^{Node}} C_i^{O} \cdot Q_{tpi}^{Asm}$ (assembling cost)
$+ \sum_{i\in N^{Pro}\cup N^{Asm}} \sum_{p\in P^{Material}} C_{pi}^{Storage} \cdot I_{tpi}^{Material}$ (materials storage cost)
$+ \sum_{i\in N^{Pro}\cup N^{Asm}} \sum_{p\in P^{Core}} C_{pi}^{Storage} \cdot I_{tpi}^{Core}$ (components storage cost)
$+ \sum_{i\in N^{Asm}\cup N^{Final}} \sum_{p\in P^{Final}} C_{pi}^{Storage} \cdot I_{tpi}^{Final}$ (final products storage cost)
$+ \sum_{(i,j)\in Conn^{Inter}} \sum_{p\in P_i^{Node}} \sum_{m\in M} C^{h} \cdot V_{pi} \cdot Q_{tpijm}^{Inter}$ (capital holding cost)
$+ \sum_{(i,j)\in Conn^{Inland}} \sum_{p\in P_i^{Node}} C^{h} \cdot V_{pi} \cdot Q_{tpij}^{Inland}$ (capital holding cost)
$+ \sum_{p\in P^{Final}} \sum_{i\in N^{Dis}} C_p^{Stockout} \cdot I_{tpi}^{-Final}$ (stockout cost of final products)

Stochastic Parameters:

S: Stochastic scenario set

T_{si}^{bang}: The disruptive event of scenario $s \in S$ breaks out at node $i \in N$ at time T_{si}^{bang}

T_{si}^{dur}: The disruptive event of scenario $s \in S$ at node $i \in N$ will last for a time period of T_{si}^{dur}

Q_{si}^{bang}: The up-bound capacity of scenario $s \in S$ at node $i \in N$ during the time period of disruption when $T_{si}^{bang} \le t < T_{si}^{bang} + T_{si}^{dur}$

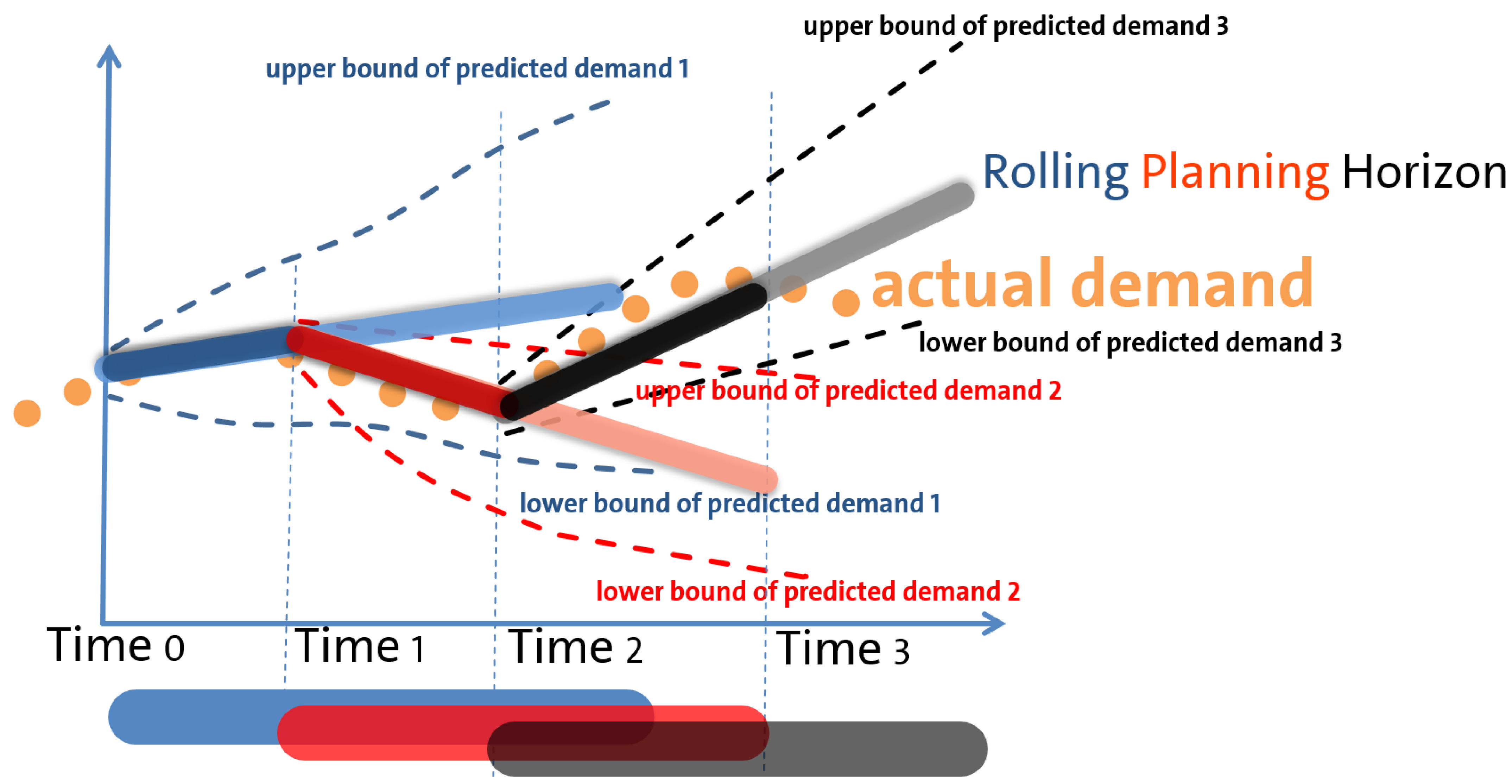
D_{stpi}^{S}: Predictive demand of final products $p \in P^{Final}$ at distribution center $i \in N^{dis}$ at time $t \in (T_0 + T_{1st}, T_f]$ under scenario $s \in S$

P_s: The probability of scenario s

A multi-stage stochastic programming model is used to determine a decision for each node of the scenario tree, given the information available at that node. The example shows a two-stage stochastic programming problem. The objective is to make the first stage supply chain plan taking into account potential catastrophic disruptions during the second stage to minimize supply chain costs for the whole considered time horizon.

Flexible Supply Chain adopted in a Rolling Planning Horizon

For the last step PYOMO, a Python-based, open-source optimization modeling language with a diverse set of optimization capabilities, is used. The high-quality feasible solutions obtained by implementing the structure of the scenario tree and the stochastic model into PYOMO are merged into a supply chain plan. This plan contains sub-plans like the purchasing plan, the production plan, the transportation plan, the distribution plan, etc. The supply chain plan is adopted into practice on a rolling horizon. a rolling horizon consists of a set of adjusted supply chain plans. Whenever there is new information available in forms of big data, the whole process of creating scenario trees and determining decisions via the stochastic programming model has to be repeated in order to obtain the set of supply chain plans. Simulation results show that supply chain plans generated in this way can help to save 5 up to 64 percent of a supply chain's costs. This has been found by analyzing the costs of supply chain plans from multi-scenario modeling by comparing three benchmarks: a pessimistic, an optimistic, and an average scenario.



References:

Fan, Y., Heilig, L., Voß, S.: Supply chain risk management in the era of big data. LNCS 9186 (Chapter 27,978-3-319-20885-5, 340044 1 En)(2015)

Fan, Y., Schwartz, F., Voß,S., Woodruff, D.: Progressive Hedging for Flexible Global Supply Chain Planning in Stochastic Environments. Optimization Methods and Software. [to be submitted on 1Dec. 2015]

Fan, Y., Schwartz, F., Voß,S.: Flexible Supply Chain Planning based on Variable Transportation Modes. International Journal of Production Economics. [Manuscript no. IJPE-D-14-01696, submitted on 30Dec. 2014] (Under review)

Fan, Y., Schwartz, F., Voß, S.: Flexible supply chain design under stochastic catastrophic risks. In: Kersten, W., Blecker, T., Ringle, C.(eds.) Next Generation Supply Chains. pp. 379{406. Epubli, Berlin (2014)

Fan, Y., Schwartz, F., Voß,S.: Flexible global supply chain planning with demand forecast revision under stochastic environments. Book of Abstracts, 17th British-French-German Conference on Optimization, London, 15-17 June 2015.

For more information on PYOMO please visit:

http://www.pyomo.org/