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Towards coordination in robust supply networks

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Abstract: Supply chains nowadays frequently face risks caused by increased environmental volatility and performance inefficiency. In this paper an integrated supply chain planning approach is suggested that combines the three aspects of *optimisation*, *risk mitigation* and *decentralisation*. The goal of this paper is to outline the research directions for industrially relevant and applicable methods for integrating robust and coordinated supply chain planning.

Keywords: Supply chain, risk mitigation, robustness, coordination, inventory control

1. INTRODUCTION AND RELATED WORKS

Recently, supply chains have became more and more globalised and lean so that they can reduce their operating costs. However, this has also decreased their flexibility and increased their vulnerability. Several cases are known when unexpected disturbances at any distant point of their supply chains could paralyse even large multinational companies due to the lack of risk mitigation and uncoordinated decision making.

The RobustPlaNet project aims at developing an innovative business approach along with a supporting technology that will change the current rigid product-based business models into collaborative and robust production networks able to timely deliver products and services in very dynamic and unpredictable, global environments. This approach will allow distributed supply networks to efficiently operate with high service levels in global markets characterised by demand and variant uncertainty, and an environment exposed to disruptive events. In this paper we investigate the theoretical background, as well as the applicability and integrability of robust supply chain planning and coordination methods.

There are numerous risk factors in supply chain planning. One of the most frequently studied type is the *demand variation and obsolescence*. The demand for a product is not only fluctuating, but can even permanently cease, e.g., in case of the development of an improved substituting product. In order to avoid unnecessary excess inventories, the ramp-down phase of the products should be considered separately and planned with special care. An other problem is the *supply time uncertainty*: material shortages can occur also due to supplier fault, transportation problems, quality problems, to name a few. Furthermore, there is also *production uncertainty* due to machine breakdowns and personnel absence that can delay production. Finally, *disasters and other unforeseen events*—e.g., natural disasters, terrorist attacks, political instability—considerably influence the supply chain operations, but they are extremely hard to predict (Simchi-Levi, 2010).

Risks can be categorised into two types: *predictable* and *unpredictable* (Simchi-Levi, 2010). The predictable risks are quite frequent, thus they can be forecasted for example by statistical methods. Such predictable types are the demand fluctuation or the scrap production. On the other hand, unpredictable risks are rare (their probability is low), but if they happen, they have huge influence. Some recent extreme natural disasters—such as tsunami, flood, volcano eruption, blizzard—, sudden changes in the economic conditions or political environment fall in this category. An important metric of disruptions is the Time-To-Repair (TTR), i.e., the time required for the affected facility to return to full capacity.

Considering risks during the supply chain planning phase can be carried out in several ways. One can for example run several randomised *simulations* in order to evaluate a plan in a stochastic environment. An other approach is to include the uncertainty into the planning model and apply a *stochastic programming* approach to solve it. Yet another possibility is the *scenario generation*, which does not require a stochastic model, but instead a number of alternative scenarios of possible disruptions in the system. Furthermore, *robust optimization* approaches aim at finding such solutions that also perform well if their uncertain parameters vary in predefined intervals.

In RobustPlaNet we define *robustness* as the ability of a system to provide the desired output even in presence of internal and external disturbances. Both uncertainties in the environment and partial failure of the system should be considered in order to call the system robust. A possible metric for supply chain robustness is the *Time-To-Survive* (TTS), which was proposed by Simchi-Levi et al. (2015). The TTS of a facility in a supply chain is the time that the customer service level can be maintained if the facility is disrupted, and the TTS of a supply chain is the minimal TTS of its facilities (the weakest link).

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There are several planning decisions in supply chains that influence the robustness. For *supplier selection*, when the decision is made for the long term, single sourcing is very vulnerable. Instead, frequently dual (or even multiple) sourcing is applied—c.f., 2-flexibility from Simchi-Levi et al. (2015). The *place and level of the inventories* are also essential for the robust planning. For example, storing large amount of finished goods might provide safeguards against supply problems, but this is usually a quite expensive solution. Sometimes *production capacity* buffers and flexibility might be necessary in order to adapt to the increased demand and avoidance of bottlenecks, but this decreases the resource utilization. *Logistic decisions*—such as choosing the applied ordering policies, frequencies, order quantities and transportation modes—also affect the vulnerability towards disruptions. Further decisions can also indirectly influence robustness, such as the applied forecasting method or the product and part pricing.

Numerous practical approaches have been proposed for supply chain risk mitigation focusing on the previously mentioned decision problems, see e.g., Tang (2006) or a recent literature review by Ho et al. (2015). Two of the most well-studied strategies are holding *protective inventory* and increasing *process flexibility*. Holding additional inventory is a straightforward way to hedge against disruptions: if the inventory is high enough to cover the demand for the duration of TTR of the disrupted facility, then it will not affect the service level, thus the supply chain can be considered robust. Note that the necessary protective inventory depends only on the TTR, thus the long lead-times of some suppliers do not increase the required inventory. Unfortunately, holding sufficient buffers can still be very expensive.

The process flexibility on the other hand, means introducing redundancy to the supply chain, e.g., when a plant or production line can build different types of products, thus the demand can be satisfied from different sources. Increasing flexibility can also be costly, and in addition, it also requires additional capacities: if there is no excess capacities in the system, the work cannot be redistributed in case of disturbances.

Simchi-Levi et al. (2015) suggests that protective inventory and process flexibility should be combined in order to provide sufficient robustness but also keep costs as low as possible. They point out that the probability of some supply chain risk are very difficult to estimate, furthermore, the resulted stochastic models are computationally rarely tractable. Therefore they suggest using a robust optimization approach by defining *uncertainty sets* for the uncertain parameters. They also suggest considering the *worst-case* possibility that helps identifying the vulnerabilities of a supply chain.

As we have just seen, robust supply chain planning is located at the intersection of optimisation and risk mitigation. Similarly, the supply chain coordination is at the intersection of (distributed) optimisation and autonomous systems. This idea is illustrated on Fig. 1. Considering robust planning and coordination together in supply chains is still a relatively unexplored research field (Lu et al., 2015). The goal of this paper is to outline the research directions for industrially relevant and applicable methods for integrating robust and coordinated supply chain planning. This paper focuses on the logistic optimization and disregards other related supplementary approaches of the project such as production optimization (Gyulai et al., 2014), lead-time reduction or required information and communication technology.

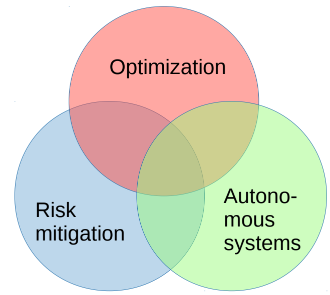

Fig. 1. Related research fields

2. INDUSTRIAL MOTIVATION

The setting of this case study is illustrated on Fig. 2. This supply chain produces electromechanical drives and its studied part consists of four stakeholders: the distribution centre (DC), the manufacturer, the inventory hub (IH) and a supplier of parts. The task of the DC is to provide the required electromechanical drives for the customers. In order to do this, it needs to make long-term (2-3 years) demand forecast aggregating across several customer areas and maintain appropriate finished good stock to satisfy the prompt demands. The manufacturer has to provide the required finished goods for the DC. Since the manufacturing process takes in average 50 days, the production is planned for the medium term, i.e., a few months ahead. For providing flexibility for production planning, some finished good buffer is held also at the manufacturer.

A required part for the manufacturing is supplied by a factory located in the Far East, which has a very long production time–approximately 8 months—, therefore their production has to be started quite in advance. In the studied case, the supplier is an external company operating in a Make-To-Order (MTO) manner, thus it is the responsibility of the manufacturer to give long-term orders based on demand forecasts. Note that such long lead-time suppliers are also typical in the European automotive industry (Zapp et al., 2012).

The transportation from the supplier to the IH also takes rather long time. The default transportation mode is by ship which takes 2.5 months, therefore the transportation also has to be planned in advance. In case of unexpected shortage however, a faster transportation alternative by plane can be chosen. By using air transportation the duration can be reduced to 3 weeks, but due to its high cost, only applied in emergency situations.

Since the inventory space at the manufacturing site is limited, the storage of the parts between the supplier and the manufacturer takes place at an IH. The IH is located close to the manufacturing site managed by an external service provider collaborating with the manufacturer. Besides the storage of the parts, the IH is responsible for choosing the transportation mode from the supplier and providing the