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Disruption-driven supply chain (re)-planning and performance impact assessment with consideration of pro-active and recovery policies

Dmitry Ivanov [a,*], Alexander Pavlov [d], Alexandre Dolgui [c], Dmitry Pavlov [d], Boris Sokolov [b,d]

[a] *Chair of International Supply Chain Management, Berlin School of Economics and Law, 10825 Berlin, Germany*
[b] *ITMO University, St. Petersburg, Russia*
[c] *Ecole Nationale Supérieure des Mines de Nantes, IRCCYN, UMR CNRS 6597, La Chantrerie, 4, rue Alfred Kastler – B.P. 20722, F-44307 NANTES Cedex 3, France*
[d] *SPIIRAS, Saint Petersburg Institute of Automation and Informatics, Russian Academy of Sciences, Russia*

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ABSTRACT

In this study, an approach to re-planning the multi-stage supply chain (SC) subject to disruptions is developed. We analyze seven proactive SC structures, compute recovery policies to re-direct material flows in the case of two disruption scenarios, and assess the performance impact for both service level and costs with the help of a SC (re)planning model containing elements of system dynamics and linear programming. In the result, an explicit connection of performance impact assessment and SC plan reconfiguration issues with consideration of the duration of disruptions and the costs of recovery has been achieved.

1. Introduction

Supply chain (SC) planning decides on directing commodity flows in the SC to efficiently balance supply and demand at the aggregate level in the medium-term planning horizon subject to a given facility location structure, capacities, customer demand, and order quantities (Dolgui and Proth, 2010; Chopra and Meindl, 2012; Costantino et al., 2012; Sawik, 2014; Ivanov et al., 2015).

In SC planning (SCP), it is manda to take into account uncertainty and risks in order to provide practically relevant problem statements and decision-oriented solutions of computational models (Wu et al., 2015). Simchi-Levi et al. (2014), Sawik (2015) and Ambulkar et al. (2015) underline crucial role of disruption events and recovery policies in SCP.

In 2000–15, SC disruptions occurred in greater frequency and intensity, and thus with greater consequences (Chopra and Sodhi, 2014; MacKenzie et al., 2014; Simchi-Levi et al., 2014). Such *disruptive risks* represent a new challenge for SC managers who face the *ripple effect* (Liberatore et al., 2012; Ivanov et al., 2014a, 2014b) subject to *structural disruptions* in the SC. The ripple effect describes the disruption propagation, the impact of a disruption on SC performance and the disruption-based scope of changes in the SC structures.

Recent studies extensively considered SCP taking into account disruption risks (e.g., Dolgui and Ould Louly, 2002; Xia et al., 2004; Snyder and Daskin, 2005; Xiao and Yu, 2006; Dolgui and Prodhon, 2007; Wilson, 2007; Chauhan et al., 2009;

* Corresponding author. Tel.: +49 (0)30 308771155.
E-mail addresses: divanov@hwr-berlin.de (D. Ivanov), alexandre.dolgui@mines-nantes.fr, dolgui@emse.fr (A. Dolgui).

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Lim et al., 2013; Ivanov et al., 2013, 2015; Dolgui et al., 2013; Sawik, 2013; Paul et al., 2014; Aloulou et al., 2014). These studies revealed that the scope of the disruption rippling and its performance impact depends both on resilience reserves (e.g., redundancies like back-up suppliers or capacity buffers) and speed and scale of recovery actions.

Despite a wealth of literature on SCP with disruption considerations, most of the existing studies consider the recovery policies under the assumption that the disrupted facilities or transportation channels do not return into the SC operation during the planning horizon. There are only a few studies that incorporate SC plan reconfiguration into the performance impact assessment. To the best of our knowledge there is no published research that considers only temporary absence of some SC elements taking into account the duration of disruptions with the capacity recovery and the costs of this recovery.

In this paper, we study a problem where elements in the multi-stage SC can be disrupted to different extents and at different times. The task is to re-plan the material flows in the SC and identify the performance impact of the disruptions taking into account the re-planning (recovery) policy. We analyze seven possible proactive policies subject to structural (i.e., back-up suppliers) and parametrical (i.e., capacity expansion) resilience actions that aim to increase the SC resilience at the proactive planning stage. Subsequently, recovery policies are developed to re-direct material flows in the case of two disruption scenarios and performance impact is assessed for both service level and costs. To perform the analysis, we formulate multi-stage SC (re)planning model containing elements of system dynamics and linear programming (LP).

The remainder of this paper is organized as follows. Section 2 analyses recent literature. Section 3 considers a case-study and proposed methodology. In Section 4, the mathematical model is presented. Section 5 is devoted to the experimental calculation of optimal SC plans. In Section 6, different actions for increasing the SC resilience are analyzed. Managerial insights are presented in Section 7. The paper concludes by summarizing the most important findings and outlining future research needs.

2. Literature review

Different approaches to protect and control SCs in regard to disruptions and to coping with uncertainty have been developed in recent years (Dolgui and Ould Louly, 2002; Dotoli et al., 2006; Chauhan et al., 2009; Peng et al., 2011; Costantino et al., 2012; Baghalian et al., 2013; Sawik, 2014). The surveys on specific aspects of these problems are presented in (Dolgui and Prodhon, 2007; Klibi et al., 2010; Dolgui et al., 2013; Aloulou et al., 2014; Fahimnia et al., 2015). In this Section, we analyze how the consideration of disruptions with recovery policies has been done in literature so far.

It is to note that different approaches have been to applier to analysis of SCP under disruptions. They include mixed integer programming (MIP), stochastic and fuzzy programming, simulation, and control theory. For the analysis we selected the recent studies that address similar problem structures (i.e., multi-period, multi-stage), time-dependent disruption considerations and/or recovery policies.

Losada et al. (2012) use a bilevel MIP for protecting an uncapacitated median type facility network against worst-case losses. The role of facility recovery time on system performance and the possibility of multiple disruptions over time is considered. Rafiei et al. (2013) developed a model for a problem statement with multiple products and many periods. They considered the levels of inventory, back-ordering, available machine capacity and labor levels for each source, transportation capacity at each transhipment node and available warehouse space at each destination. The problem also considered the facility fortification by taking into account the back-up supplier with reserved capacity and a back-up transhipment node that satisfied demands at higher prices without disruption facility. The solution to the model is based on a priority-based genetic algorithm. Choi (2013) applied mean-risk model to SC risk analysis in retail industry.

Gedik et al. (2014) model disruptions and train re-routing actions in a coal supply chain network and assess impacts of disruptions in terms of transportation and delay costs using a two-stage MIP model. An "interdictor" chooses a limited amount of elements to attack first on a given network, and then an "operator" dispatches trains through the residual network. The MIP model explicitly incorporates discrete unit flows of trains on the rail network with time-variant capacities. A K-th shortest path algorithm is used to enumerate all routes between points. The authors consider a real coal rail transportation network and generate scenarios to provide tactical and operational level vulnerability assessment analysis with incorporation of rerouting decisions, travel and delay costs analysis, and the frequency of interdictions of facilities for the dynamic rail system.

Costantino et al. (2012) presented a hierarchical approach to the strategic supply chain design addressing supply planning and allowing the improvement of the manufacturing supply chain agility in terms of ability in reconfiguration to meet performance, and considering the supplier capacity constraints. The approach employs digraph modeling and integer LP to optimal supply chain design. The authors avoid stochastic models by aggregating deterministic product flows within the integer LP model.

Sawik (2013) developed a stochastic programming model to integrated supplier selection, order quantity allocation and customer order scheduling in the presence of SC disruption risks. In the study by Madadi et al. (2014), a problem of supply network design under risk of supply disruptions is considered. Tainted materials delivery disruptions are modeled as events which occur randomly and may have a random length. A mixed-integer stochastic model is proposed and solved by a meta-heuristic algorithm. Torabi et al. (2015) propose a bi-objective mixed two-stage stochastic programming model for supplier selection and order allocation problem under operational and disruption risks. The model considers several proactive strategies such as suppliers' business continuity plans, fortification of suppliers and contracting with backup suppliers.

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