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Production and interplant batch delivery scheduling: Dominance and cooperation

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ABSTRACT

In this paper, we consider scheduling problems in a supply chain with two agents, a manufacturer and a third-party logistics (3PL) provider. The manufacturer has to process a set of jobs at the upstream stage and at the downstream stage. The 3PL provider is in charge of transportation of semi-finished products from the upstream stage to the downstream stage. The manufacturer's objective is to minimize makespan $C_{\max}$ and the 3PL provider's objective is to minimize transportation cost TC. We investigate three scenarios, corresponding to different types of contract: (i) decentralized scenario with strict responsiveness; (ii) decentralized scenario with flexible responsiveness; (iii) centralized (cooperative) scenario. We provide exact polynomial-time algorithms or prove the NP-completeness of the scheduling problems in these three scenarios. Moreover, we evaluate and compare various scenarios through a large set of computational experiments. The results show that cooperation may bring significant benefits to both actors. The benefit for the 3PL provider is particularly high if compared to situations in which the manufacturing sequence is fixed. Also the manufacturer can benefit from relaxing the job-by-job responsiveness constraint in favor of an integrated schedule which appropriately accounts for the role of the 3PL provider.

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1. Introduction

One of the key issues in supply chain management is decision coordination among involved actors, i.e., suppliers, manufacturers, third-party logistics (3PL) providers, and customers.

In this paper we focus on a two-stage supply chain in which there are two agents, namely a manufacturer, who owns the two stages, and a third-party logistics (3PL) provider, to whom the manufacturer outsources transportation from one stage to the next. The two stages are modeled as single machines, so indeed the system is modeled as a two-machine flow shop with interstage transportation. Given a set of jobs, each requiring a certain processing time at the two stages, the problem is therefore to schedule production and transportation under various arrangements between the manufacturer and the 3PL provider, properly accounting for their objectives. Here we consider that the manufacturer's objective is makespan minimization, while the 3PL provider is concerned with minimizing its costs.

The manufacturer may require the 3PL provider that each order be delivered within a certain time T from its release at the upstream stage. Small values of T enforce high *responsiveness* of the 3PL provider, which is desirable for the manufacturer in order to reduce the production makespan. However, this may entail higher costs for the 3PL provider. This conflict motivates the need for coordination between production scheduling and interplant distribution scheduling. Furthermore, in our globalized world, many firms have now multiple plants (possibly spread over different countries), in order to reduce production costs and to expand their production capacity. Therefore, in a global supply chain, a need arises to concurrently address planning, scheduling, and distribution. Moreover, as more than 70% of the companies worldwide now rely on 3PL providers for their daily distribution and other logistics needs (Langley et al., 2005), coordination between the manufacturer and the 3PL provider becomes critical to the overall system performance.

In this paper we investigate various arrangements between the two parties. Precisely, we analyze:

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- two decentralized scenarios, with two different coordination mechanisms, in which the manufacturer imposes two different restrictions, called *strict responsiveness* and, respectively, *flexible responsiveness*,
- a centralized scenario in which the parties can actually cooperate to reach a mutually acceptable overall solution.

For each scenario, we provide complexity results and solution algorithms for the resulting optimization problems. Moreover, we report the results of experiments concerning the potential benefits of the centralized scenario.

This paper is organized as follows. In Section 2, we review relevant literature and specify the contribution of our paper. In Section 3, we formally describe the problems and introduce notation and terminology. Section 4 is devoted to decentralized scenarios, Section 5 is devoted to the centralized scenario. In Section 6, we evaluate and compare the various scenarios through a large set of computational experiments. Finally, Section 7 contains some conclusions and suggestions for future research.

2. Literature review

In this section we review relevant literature and specify the contribution of this paper in the context of supply chain management.

Supply chain coordination and scheduling: In the huge literature on models for supply chain management, many authors concentrate on strategic and tactical coordination (e.g. Sarmiento and Nagiy, 1999; Erengüç et al., 1999). Thomas and Griffin (1996) first point out the need for research addressing supply chain issues at an operational level rather than a strategic level. This has triggered a large amount of research on supply chain coordination at the operational level. Most of these papers address the case in which different stages of a supply chain belong to different agents, possibly having distinct, or even conflicting, objectives. Broad literature reviews can be found in Hall et al. (2008) and Aydinliyim and Vairaktarakis (2011). Hall and Potts (2003) provide the first study of supply chain scheduling. They consider the coordination between scheduling, batching and delivery, both at a single stage and between different stages of a supply chain. They show that substantial cost reductions can be achieved through cooperation between the agents. Selvarajah and Steiner (2009) and Steiner and Zhang (2009) propose approximated algorithms for the suppliers scheduling problem defined by Hall and Potts (2003). Agnetis et al. (2006) study the coordinated scheduling problem between a supplier and several manufacturers with consideration of an intermediate storage buffer allowing limited resequencing between the two stages. Tang et al. (2014) study an integrated charge batching and casting width selection problem arising in the continuous casting operation of the steelmaking process at Shanghai, China based Baosteel.

In this research area, several articles address conflict and coordination issues among agents in various different scenarios: between several suppliers and a manufacturer (Chen and Hall, 2007), between a manufacturer and a distributor (Manoj et al., 2008), and between two consecutive stages in a production line (Manoj et al., 2012). Several articles use both combinatorial optimization as well as game-theoretic models to address the supply chain scheduling issues. Aydinliyim and Vairaktarakis (2010) utilize the cooperative game theory to address a capacity booking problem faced by multiple manufacturers each outsourcing certain operations to a common third-party firm. Cai and Vairaktarakis (2012) and Aydinliyim et al. (2014) consider the same problem with other objective functions. Aydinliyim and Vairaktarakis (2013) study a relative time-sensitive capacity allocation issue with subcontracting setting, where processing at a third-party is optional.

Integrating production and outsourced outbound distribution: Most supply chain scheduling models do not explicitly model transportation capacity issues among different stages of a supply chain. However, in the current logistics and supply chain, delivery capacity is often a bottleneck, creating the need for delivering products in batches by independent partners like Third Party Logistics (3PL) providers. According to Eurostat data 2012 (Palmer et al., 2012), about 24% of all road freight kilometers driven in Europe are empty vehicles and the average vehicle is loaded only to 56% of its capacity in terms of weight. This may be due to increasing competition, that forces manufacturers and retailers to make products quickly available to customers and, consequently, ask the 3PL providers for high responsiveness. Considerations of this type have led to a considerable amount of research devoted to supply chain scheduling models in which distribution decisions are integrated with production. A large variety of such models has been classified under the unitary framework of integrated production and outbound distribution scheduling (IPODS) problems, and thoroughly reviewed by Chen (2010). In these models, besides the agents owning various stages of the supply chain, several transportation issues are explicitly modeled, including various shipment methods, contractual agreements, transportation modes, routing considerations, etc. A more recent review about IPODS problems has also been included in the work of Ullrich (2013). A comprehensive review involving integrated production and distribution planning at both the tactical and operational decision problems has been proposed recently by Reimann et al. (2014).

Integrating production and outsourced interplant transportation: In the vast IPODS literature, it is commonly assumed that all products/orders are produced at a single plant, whereas, in a global supply chain, a product can be processed at different plants located at different geographical locations. So, even if transportation is outsourced to an independent 3PL partner, two consecutive stages of the supply chain may belong to the same manufacturer, and this may significantly affect model structure and objectives. This case is referred to as *interplant* distribution. In some cases, the situation is modeled as a 2-machine flow shop scheduling problem with various types of transportation considerations. This is the case, among the others, of Lee and Chen (2001), Lee and Strusevich (2005), Tang et al. (2010), Gong and Tang (2011), and Aloulou et al. (2014). However, there are not many articles specifically addressing transportation outsourced to a 3PL provider and the corresponding coordination mechanisms, even if this is apparently a very common practice among companies (Langley et al., 2005; Tezuka, 2011). Among them, Li et al. (2008) consider a make-to-order consumer electronics supply chain, in which production is constrained by due date imposed by the 3PL provider. Zhong et al. (2010) study an integrated production/distribution scheduling problem, in which the 3PL provider specifies various shipping times for different vehicles. In a recent paper, Agnetis et al. (2014) propose a set of models for coordinating production and interplant distribution, focusing on the problems faced by the 3PL provider when the manufacturer enforces a certain responsiveness constraint, i.e., requires that each product be delivered within a certain time from its release.

The contribution of this paper: This paper deals with coordination between manufacturer and 3PL provider with outsourced, interplant transportation. The aim of the paper is to allow comparison of various different scenarios, corresponding to different coordination mechanisms (i.e., contracts). We analyze the computational complexity of the induced models and evaluate the possible benefits of cooperation through experiments. We also elaborate on the quality of certain compromise solutions that can be achieved when manufacturer and 3PL provider decide to cooperate.

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