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Dynamic expediting of an urgent order with uncertain progress

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ABSTRACT

A supplier manages an urgent order with uncertain progress for which her client has set a deadline for its completion. The supplier observes in real time the order progress and chooses dynamically the effort level, such as manpower level, to expedite the order. Her problem is to identify expediting policies to minimise her expected cost, given by two costs in trade-off with each other: an effort level cost and a one-time penalty cost for late completion of the order. We formulate this problem using a discrete stochastic dynamic programming framework and obtain an optimal expediting policy for it.

By conducting a worst-case analysis, we show that decreasing the level of flexibility, interpreted as the supplier's ability to update effort levels more often, may lead to a large increase in the costs of managing the order. We refine the problem formulation by modelling the case in which the supplier takes into account the negative effects of late order completion on her client using a penalty cost charged every period the order is delayed. We find an optimal policy for this case, by solving two dynamic programming problems sequentially. For both problems, we show that in presence of certain assumptions, there is an optimal expediting policy for which effort levels are non-increasing in the order progress. Finally, using a simulation study based on a car seat assembly case, we compare the performance of the two policies.

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1. Introduction

Suppliers often receive urgent orders which are critical for their business. For example, automotive manufacturers, faced with sudden surges in consumer demand, may in turn place urgent orders of components to their suppliers (Reed & Simon, 2010). Similarly, aerospace manufacturers may anticipate the delivery of planes in an effort to please airline companies, relying on their suppliers to urgently deliver the components for production (Wilhelm, 2016). Both these examples show that suppliers, by managing urgent orders effectively, can positively influence future business relations with their clients. Suppliers face the problem of meeting deadlines for orders whose progress is uncertain, because of disruptions and productivity problems. To manage such orders effectively, suppliers can monitor them and dynamically choose whether to allocate extra resources to accelerate their progress. Auto-id technologies can facilitate this procedure, known as dynamic expediting (Selko, 2008). In practice, dynamic expediting decisions are often dealt without codified rules because the time pressure leads to unstructured decision-making processes.

Managing urgent orders effectively is critical to suppliers' business. We argue that suppliers can achieve effective urgent-order management by making dynamic expediting decisions in a structured manner. For this reason, we aim at providing guidance on how to manage urgent orders using dynamic expediting. In this article we consider orders arising from urgent requests made by clients, as in Chevalier, Lamas, Lu, and Milnar (2015). However, some of the guidance we provide could also be useful when scheduling problems or production uncertainties trigger regular orders to become urgent.

We study the novel problem of devising dynamic expediting policies for an urgent order. Dynamic expediting has been mostly analysed by studies investigating inventory policies in multi-stage supply chains. Our approach differs from these studies in two main aspects. First, these studies consider expediting as an action to safeguard companies from demand variability, but generally not from lead-time variability, as we do in here. Second, these studies do not take into account deadlines for order deliveries, an element which we consider in our study. In Section 2, we present previous contributions that are relevant for this study.

In our problem, a supplier processes an urgent order, such as an indivisible lot of components. This lot is indivisible by nature or because of a managerial choice; for example the supplier keeps all components together to facilitate their tracing. The supplier already made lot-sizing and reorder decisions and only chooses

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order expediting policies. The order progress is not constant, but random, because of disruptions, efficiency, and yield problems. The supplier, with the support of tracking technologies, monitors the order progress periodically. Based on this information, she decides the effort to invest in the order. A personal communication between the authors and the general manager of sales and marketing for Sanden International Europe highlights that suppliers in the automotive industry commonly employ this practice to manage urgent orders (Coulson, 2016).

More effort invested corresponds to higher costs and, in expectation, to higher order progress accomplished. For chiefly manual tasks, we find reasonable to assume that the supplier can change dynamically the effort invested in the order. The supplier can increase the effort level by diverting personnel working on other orders. Therefore, the supplier can estimate the effort cost as the opportunity cost of these workers, implicitly assessing the effect of expediting on other orders. We assume that the supplier manages the urgent order with priority over all other orders because it is business-critical. For this reason, we argue that the supplier makes expediting decisions on the urgent order independently from the progress of other orders. Therefore, we do not explicitly model the effect of expediting decisions on the other orders. Finally, if the urgent order has not finished by a deadline agreed with a client, the supplier faces an actual or estimated penalty cost. Our problem description is general and has applications in various contexts. We illustrate how to operationalise it for two cases rather different from each other: the assembly of car seats and the production of heavy machinery. Car seat assembly takes place on mostly manual production lines. In this context, the order is a lot of product and its progress could be measured by the number of units assembled from that lot. When calculating the order progress, we could ignore the work-in-progress, which is negligible because of the short processing times. Operators scan completed products using auto-id technologies, automatically updating the count of units assembled. The car seat assembler could increase the effort level by assigning more than one assembly line to the production of the order. In this context, the effort level could be the number of lines assigned to the production of the lot. For heavy machinery assembly, the order could be a single machine. Assuming that the production process could be divided in tasks with equal work content, the order progress could be measured by the number of tasks completed. Operators scan the machine with auto-id technologies each time a task is completed, updating the count of the tasks performed. In this context, the effort level could be the number of operators assigned to perform a task.

In Section 3, we formally formulate this problem. Clients often do not specify penalty costs for urgent orders. For this reason, in Section 5 we refine the problem formulation by modelling the case in which the supplier takes into account in her penalty function the negative effects of late order completion on her client. We solve both problems and investigate how the sequence of effort levels changes in the order progress, proving some interesting monotonicity results for the optimal policies. In this study, we assume that the supplier tracks the order progress and updates the effort level at each time period. However, for some activities and tasks, especially if these are partially automated, it may not be possible for the suppliers to be so flexible in changing the effort levels. Cognisant of this limitation of our study, in Section 4 we discuss the value of flexibility, which we define as the organisation's ability to change effort levels more often. In Section 6, we introduce a simulation study based on a car seat assembly case. In this study, we compare the performance of the policy obtained in Section 3 against the one of the policy obtained in Section 5. In Section 7, we include the concluding remarks. All the proofs of the results are in the Appendix.

2. Relevant work

This research contributes to the literature on expediting decisions and especially to those studies analysing how expediting could mitigate operational risks arising from lead-time variability. We review previous research on expediting in make-to stock and make-to-order systems. Then, we discuss how our model relates to previous studies.

In make-to-stock systems, the use of expediting upgrades units in transit to faster delivery modes, triggering urgent deliveries. The majority of make-to-stock literature on urgent deliveries focuses on emergency orders, additional orders usually placed later than regular orders to avoid inventory shortages. Most of these studies analyze the use of express orders in response to demand variability, with fewer contributions investigating their use in response to lead-time variability, such as the study of Kouvelis and Li (2008). They assume that real-time order progress information is available to decision maker, a setting similar to the one we study.

In the literature on expediting in make-to-stock systems, we note that some of these studies consider expediting as a modelling assumption to allow all orders to be delivered on time, as in Huggins and Olsen (2003). These contributions are not closely related to our research. Instead, we review those studies explicitly determining expediting policies based on the current information on the supply chain, including inventory levels, demand or supply conditions. These studies determine expediting policies in single-stage, two-stage and multi-stage supply chains.

Bookbinder and Çakanyildirim (1999), Gallego, Jin, Muriel, Zhang, and Yildiz (2007) and Chiang (2010) analyse expediting decisions in single-stage make-to-stock systems operating according to an order-quantity/reorder point-type policy. Bookbinder and Çakanyildirim (1999) obtain optimal conditions for a system with constant demand and stochastic lead times, made endogenous by considering expediting factors. Gallego et al. (2007), for a system facing random demand, prove that, at optimality, inventory managers should expedite orders according to a threshold policy, assuming that the time between order reception and customer demand can be modelled using an Erlang distribution. Chiang (2010) also identifies an optimal threshold policy for a system in which allocating part of an outstanding order to a faster, non-zero lead-time expediting option is allowed. Fu, Xu, and Miao (2013) consider a news-vendor problem with many expediting options.

Minner, Diks, and De kok (2003) provide approximate solutions for a two-stage inventory system with one central depot and many retailers facing Mixed-Erlang demand. The depot could expedite outstanding orders in case it has insufficient stocks to satisfy retailers. However, the expediting outcome is not known in advance and is modeled after a stochastic process taking into account the number of orders expedited and the age of the orders.

Studies on expediting decisions in multi-stage supply chains introduce the idea of dynamic management of orders, in which order progress is checked at each time period and each stage and expediting decisions are made accordingly. Lawson and Porteus (2000) analyse a periodic-review multi-stage make-to-stock system facing random demand. They assume regular lead times between adjoining stages to be one week and expediting to be instant. They make decisions from the most upstream stage to the one closest to consumer demand, allowing units to be shipped instantly many stages downstream in the supply chain. They assume expediting costs to be linear in the number of stages across which units are shipped. They show top-down base stock inventory policies to be optimal. In such policies, decisions of a particular stage are constrained by the decisions made in the stages farther up in the supply chain. Muharremoglu and Tsitsiklis (2003) and Kim, Klabjan, and Simchi-Levi (2007) extend Lawson and Porteus model and find

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