



# Supply chain risk mitigations with expedited shipping<sup>☆</sup>



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## ABSTRACT

We study supply chain risk mitigations by incorporating expedited shipping. The firm we consider can source from two suppliers—one is unreliable while the other is perfectly reliable but more expensive. It intends to mitigate the potential risks caused by random disruptions at the unreliable supplier by adapting its risk mitigation policy based on the supplier's disruption factors, such as the expected disruption length and expected availability, together with other information on costs and transportation time. This work generalizes the research of Tomlin [32] who investigated a similar problem without expedited shipping. We show how the expedited shipping option influences the optimal mitigation strategies, and conclude that a firm's optimal risk-mitigation strategy is sensitive to its capability of expediting shipments. We also identify the cost-saving feature of expedited shipping for supply chain risk mitigations, and demonstrate that it is a good alternative when the cost of maintaining flexible capacity at the reliable supplier is high. These characterize the importance of considering expedited shipping in supply chain risk mitigation, and offer insights for developing new transportation modes with expedited shipping in practice.

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## 1. Introduction

Managing supply chain risks/disruptions has been a primary research focus in supply chain management for many years. We refer interested readers to Snyder et al. [26] for a comprehensive review of the literature on managing supply chain disruptions. A representative study in this field is carried out by Tomlin [32], who systematically compares different risk-mitigation strategies, such as inventory mitigation (in which firms hold extra inventory to protect against supply disruptions), contingent rerouting (such that firms use reliable but more expensive suppliers as backups, and order from them when unreliable suppliers are disrupted), and sourcing mitigation (ordering from reliable but more expensive suppliers), and proposes optimal mitigation strategies under different scenarios. He considers not only the case with infinite extra flexible capacity, beyond the regular capacity, at the reliable supplier, but also the restrictive case such that the reliable supplier only has limited flexible capacity to be used by the firm during emergency.

In this paper, we consider a similar problem setting as that of Tomlin [32], in which one firm can order from two suppliers. One

supplier is unreliable, while the other is perfectly reliable but more expensive. We generalize Tomlin's work by considering expedited shipping between suppliers and the firm. We intend to learn how the option of expedited shipping from suppliers to the firm influences the firm's optimal risk-mitigation strategies, and what the value of expedited shipping is in terms of potential cost savings to the overall operations.

Expedited shipping, though often associated with higher costs, is very common and widely implemented in industry. For example, as Taghaboni-Dutta [28] points out, managers often tend to use expedited air shipments when there is a delay in international shipments. Terry [30] analyzes various successful expedited shipping practices, such as Preferred Less-Than-Container Load service by UPS, Columbus, Ohio-based AirNet Cargo Charter Services' Scheduled Package Delivery, and the expedited shipping service by YRC Freight based in Overland Park, Kansas. Based on these analyses, Terry concludes that more shippers choose expedited shipping now because it has evolved from a super-premium service to a supply chain problem-solver. Accordingly, logistics service providers start offering a range of new service options, from expedited ocean to two-driver ground services, to help shippers balance speed and cost. Terry emphasizes the benefits of expedited shipping, such as lowering inventory carrying costs, eliminating the delay and adding flexibility to production planning, which can sometimes negate the higher costs. This trend and new understanding in industry bring us the consideration of how

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to take advantage of these benefits of expedited shipping in supply chain risk mitigations, in which it is critical to balance the inventory, capacity and delay costs.

The idea of expedited shipping has also been incorporated in many research works, such as Huggins and Olsen [15], Caggiano et al. [4], and Zhou and Chao [43]. However, how this shipping option changes firms' optimal risk-mitigation strategies is still a new topic that has not yet been fully investigated. Based on what mentioned above, this option is apparently a potential approach that firms would like to consider if supply disruptions occur and provides firms with extra flexibility in terms of a "time buffer". This would free the firm from having to hold high safety stock as "inventory buffer", or maintain too much extra production capacity to protect against supply disruptions if the cost of holding "inventory buffer" or maintaining "capacity buffer" is high. In addition, with this option, when the costs associated with the sourcing mitigation or contingent rerouting are high, the firm may want to wait to see if the supply disruption can be recovered quickly and then use expedited shipping to keep everything on time. These imply that expedited shipping might bring significant cost savings to firms' supply chain risk mitigations.

To this end, we theoretically study this supply chain risk mitigation problem by following the common research framework used by many quantitative research works in the relevant literature (e.g., [32,19]). In particular, we consider the supply-side disruption risk caused by the unreliable supplier's random disruptions and recoveries, and the consequent impacts on the firm's service quality and response time in its business with customers. Any resulting delay is measured in terms of penalty cost. To keep its operating cost low, the firm shall adapt its risk-mitigation strategy corresponding to the scenarios characterized by the unreliable supplier's random disruption factors, such as the expected disruption length and expected availability, and other cost and transportation time factors. Besides the risk-mitigation approaches studied by Tomlin [32], including inventory mitigation, contingent rerouting, and sourcing mitigation, we also take the potential expedited shipping option into account. By comparing the costs associated with these risk-mitigation options, as well as combinations thereof, we conclude that the consideration of the expedited shipping option often greatly influences the optimal risk-mitigation strategy, which is sensitive to the firm's capability to expedite the shipments. We also demonstrate the value of expedited shipping by showing its great cost-saving feature under different scenarios, especially when the unreliable supplier has short disruptions. This implies that when the cost of holding inventory at the firm or maintaining flexible capacity at the reliable supplier is high, expedited shipping turns to be a decent option that the firm might want to consider to mitigate the supply risks. These insights are also helpful when firms develop new transportation modes in practice.

The rest of this paper is organized as follows. Related literature is reviewed in Section 2. We introduce the basic assumption and notation in Section 3. The model is formulated and extended in Sections 4 and 5, respectively, and some properties of the model are identified in these two sections as well. Numerical studies are carried out in Section 6 for managerial insights regarding cost savings brought by expedited shipping and how the expedited shipping option influences the optimal risk-mitigation strategies. The paper is concluded in Section 7. All proofs for the conclusions in this paper are provided in the Appendix.

## 2. Literature review

Two streams of research are particularly related to this study. The first is the research on sourcing/risk-mitigation strategies under

supply uncertainty. Tomlin and Wang [31] consider both mix-flexibility and dual-sourcing strategies in their research on unreliable supply chains for multiple products. Tomlin [32] studies a problem in which the firm can source from a cheap but unreliable supplier or an expensive but reliable supplier. If the cheap supplier is disrupted, the reliable supplier can offer flexible capacity that goes beyond its regular capacity at a higher charge. This work is extended by Qi [23] with the consideration of the potential waiting before using the flexible capacity at the reliable supplier. Yu et al. [42] consider how supply disruption risks influence the choice of the single and dual sourcing methods in a two-stage supply chain with price-sensitive demand. Tomlin [33] examines the influences of supply learning on sourcing strategies. Recently, Nejad et al. [22] investigate a contingency rerouting problem for a supply chain subject to random disruptions. They intend to determine the appropriate response speed of a reliable backup supplier with volume-flexible production facilities, by considering the impacts of response time and congestion.

Babich [2] investigates a two-supplier problem that takes the differences of supplier lead times into consideration. The firm can defer its ordering-quantity decision from the supplier with a shorter lead time until it partially observes the uncertainty associated with the other supplier. This makes the supplier with a shorter lead time a contingent source in a certain sense. Similarly, Chopra et al. [5] consider a two-supplier problem in which the cheap supplier is subject to both yield uncertainty and random disruptions and the expensive supplier is perfectly reliable. By paying the reliable supplier a premium, the firm can order from it after observing the order-fulfillment state of the unreliable supplier. Giri [12] further develops a similar problem by studying it in the context of a risk-averse firm.

Dada et al. [9] consider a newsvendor problem, in which the retailer diversifies the risk of supply uncertainty by applying multiple sourcing from suppliers that differ in cost and reliability. The newsvendor problem setting with two or more suppliers is also adopted in other research works. Burke et al. [3] study a newsvendor-related problem for a firm with multiple suppliers. Their interest is the impact of supply and demand uncertainties on the optimal sourcing decision. Wang et al. [35] study a single-product newsvendor problem with unreliable suppliers for which the authors compare the process-improvement strategy (i.e., to improve supplier reliability) and the dual-sourcing strategy. Xanthopoulos et al. [41] investigate single period newsvendor-type inventory models and focus mainly on the trade-off between inventory policies and disruption risks in a dual-sourcing supply network. Both risk-neutral and risk-averse decision-makers are considered.

Schmitt [24] works on a multi-echelon distribution system with uncertain supply and deterministic demand. She formulates the service level as a function of any given combination of various mitigation strategies and evaluates the impact of various mitigation strategies on service levels. Micheli et al. [19] propose a theoretical decision framework that includes relevant elements derived from the literature on supply chain risk management. They further provide a general quantitative decision support system upon this decision framework to select mitigation strategies for supply chain risks.

Allon and Miegheem [1] propose a practical sourcing strategy by considering a firm that has access to a responsive nearshore source and a low-cost offshore source. The authors analyze a tailored base-surge sourcing policy that combines push and pull controls by replenishing at a constant rate from the offshore source and producing at the nearshore plant only when inventory is below a target level. Interested readers are also referred to Allon and Miegheem [1] for a detailed literature review on dual-sourcing strategy in terms of both periodic and continuous review models.

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