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An optimization framework for improving supplier delivery performance

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ABSTRACT

Given the growing importance of supplier delivery performance in buyer–supplier alignment and end-to-end fulfillment of supply chains, we investigate the managerial implications of a buyer who financially invests to improve a supplier's delivery performance by demonstrating an optimization model for the buyer's investment decision to reduce untimely delivery. We illustrate how improving supplier delivery performance leads to better supplier management. Our analysis utilizes the ingenious zeta transforms widely used in engineering to showcase its applicability in today's complex supply landscapes that use multiple suppliers to create efficient frontiers for diverse sourcing initiatives.

1. Introduction

The average manufacturing firm spends over 50% of its revenues on purchased inputs. With companies continuing to increase the volume of outsourced work across industries, this percentage is likely to rise [1]. Industries that rely on innovation and new product development (NPD) have justified the role of knowledge sharing with suppliers as critical to the improvement of overall supply chain performance [2–4]. Consequently, suppliers continue to have a significant impact on the delivery of a company's products and/or services [5]. Given the importance of "time-to-market" in today's disruption-prone global logistics and the predilection of modern business philosophies towards cycle-time minimization, improving supplier delivery performance holds critical importance to buyer–supplier alignment and the deployment of a truly integrated supply chain [6]. In this paper, we investigate the managerial implications of a buyer who financially invests to improve its supplier's delivery performance.

This paper presents a modeling framework that can be used to support the long-term improvement of supplier delivery performance within a supply chain. The optimization model designed in this work links supplier-delivery-related costs that accrue from untimely (early and late) deliveries to continuous improvement (CI) in supplier selection and management. These decision outcomes are integral to transportation efficiency, the low hanging fruit to a new approach of collaboration in supply management – horizontal collaboration, i.e., collaboration *across rather than along the supply chain* [7]. This paper contributes to improvement of supplier delivery performance in the following ways. *First*, since penalty costs for untimely delivery are incurred based on deliveries scheduled over a planned time horizon, it is imperative that cost-based delivery performance models designed around penalty costs for early and late deliveries incurred within a time horizon consider the *time value of money*. Cost-based optimization models for evaluating supply chain delivery performance have been

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proposed by several researchers [8–14]. A review of these models indicates that the time value of investment dollars for improving delivery performance is lacking. The model framework presented herein bridges this gap and advances the literature on continuous improvement of delivery performance by realizing the true present worth of penalty costs to a buyer due to future untimely deliveries from a supplier. This modeling attribute is essential for justifying financial investment to support CI in supplier delivery performance.

Second, our model addresses *supply chain agility* [15]. We conceptually show the benefit to supplier delivery performance when the penalty cost of untimely (early and/or late) delivery is reduced. The reduction in penalty cost of untimely delivery is modeled as an exponential decay function using a zeta transformation methodology which directly incorporates the time value of money in this analysis. We present different profiles for improving untimely delivery based on different improvement rates. This approach to improving delivery performance reduces penalty costs due to untimely delivery, while increasing overall responsiveness and agility of the supply chain.

Third, our model addresses *supply chain alignment* [15] by incorporating continuous improvement in delivery performance from an integrated buyer–supplier perspective. Continuous improvement of the buyer is addressed by measuring the financial impact of "buyer neglect", which explains the opportunity cost of failing to improve delivery performance when costs due to untimely delivery are incurred. Continuous improvement of the supplier is based on the underlying contention that improvement comes at a cost. We therefore discount the magnitude of the buyer's investment in delivery improvement as a function of the supplier's rate of improvement. Suppliers who demonstrate a higher rate of improvement are rewarded with a proportional decrease of the cost to the buyer for improvement, and vice versa. In reality, suppliers that improve their delivery performance will incur less penalty costs in the short term and enhance their long-term attractiveness to the buyer by continuously improving their delivery performance.

Fourth and finally, guided by a budget constraint for continuous improvement in supplier delivery performance, we: (i) optimize the amount a buyer invests for spending on CI as a means to gauge a supplier's ability in meeting an optimum improvement rate and, (ii) determine the optimal point in time where delivery improvement should start by minimizing overall cost to the buyer while maximizing supplier delivery performance. Thus, the optimization model developed in this paper contributes a budget-constrained managerial decision tool for evaluating the financial impact to both the buyer and the supplier who engage in a CI program to improve supplier delivery performance.

The rest of this paper is arranged as follows: Section 2 provides a theoretical approach to improving delivery performance. In this section, we introduce continuous improvement to a penalty cost model by incorporating present worth and a profile for improving untimely deliveries. The opportunity cost of failing to consider penalty costs for untimely deliveries is addressed in Section 3. In Section 4, we discuss the cost to the buyer for pursuing supplier delivery improvement. Section 5 introduces an optimization model for buyer spending to balance the opportunity cost of neglecting improvement and the cost incurred due to pursuing supplier delivery improvement. Finally, Section 6 discusses implications of this research and provides a summary conclusion.

2. A theoretical approach to improving delivery performance

The delivery process in a supply chain is a key component of overall supply chain operations. The performance of the delivery process within a supply chain directly impacts sourcing decisions as well as customer satisfaction levels. Delivery performance is viewed as a strategic level supply chain performance measure [16–18] and recent empirical research has identified the positive role that delivery performance plays in the overall competitiveness of an organization [19,20]. For comprehensive reviews of supply chain delivery models the reader is directed to [21,22].

We model continuous improvement of delivery performance along two dimensions. First, we utilize the time value of money to capture the temporal nature of penalty costs for early and late delivery over a planned time horizon. Second, we directly incorporate delivery improvement into our model using a discounted delivery penalty cost function that takes into consideration the delivery improvement of suppliers achieved at discrete steps within the overall planning horizon. The following subsections detail the development of our modeling approach along these two dimensions.

For the sake of standardization and brevity as well as to enhance readership, we have provided a consolidated notations list (Table 1) to guide the reader through the equations. The notations in table 1 are described in the same order they appear in the equations. Each equation presented in the subsections below builds on the previous one. As such, there are a few notations that are common to many equations. We have only mentioned new notations under an equation to avoid redundancies.

2.1. Present worth of investments for delivery improvement

Laplace transformation theory has been widely used in the fields of physics and engineering since the late 1930s. Grubbström [23] was one of the first researchers to see the application of Laplace transforms in modeling the present worth of financial cash flows. Building on this foundation paper, zeta transforms (which may be viewed as a variant of the Laplace transformation) offer considerable advantage in the modeling and analysis of economic situations involving discrete time series of cash flows and have been adopted by several researchers [24–27]. In analyzing penalty costs due to untimely delivery, we are looking at multiple deliveries from suppliers over a set time horizon (typically yearly). Given the discrete nature of deliveries made by a supplier, we adopt zeta transforms to capture the present value of the cost stream for penalty costs associated with late deliveries.