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Recent Trends in Supply Chain Delivery Models

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Abstract**—**A review of the literature on supply chain delivery models which use delivery windows to measure delivery performance is presented. The review herein serves to meet the following objectives: (i) provide a synthesis of previously published literature on supply chain delivery performance models, (ii) provide in one paper a consolidation of research that can serve as a single source to keep researchers up to date with the research developments in supply chain delivery models, and (iii) identify gaps in the modeling of supply chain delivery performance which could stimulate new research agendas.

Keywords**—**Delivery performance, Delivery window, Supply chain delivery models, Supply chain performance.

I. Introduction

MANY firms have adopted the Supply Chain Management (SCM) philosophy as a strategy to advance their market competitiveness. The SCM philosophy advocates integrating production planning, sourcing, logistics, and customer relationship management into an integrated and seamless set of value-adding activities that spans both internal operations within the firm and external operations with the firm's partners in the supply chain. Performance measurement plays a critical role in the operation of a supply chain and several researchers have investigated the importance of performance measurement in SCM (see for example [1]-[3]).

In this paper we address one aspect of overall supply chain performance, delivery timeliness to the end customer in the supply chain. The delivery process within a supply chain is a critical concern in the operation of a supply since delivery performance directly impacts customer satisfaction and the selection of raw material vendors and third party logistics providers [4]. Within the hierarchy of supply chain performance measures, delivery performance is classified as a strategic level supply chain performance measure [5].

The objective of this paper is to provide a review of supply chain delivery performance models which use delivery windows to evaluate delivery performance. A delivery window is defined as the difference between the earliest acceptable delivery time and the latest acceptable delivery time (see Fig. 1). Benchmarks in time are used to classify deliveries as being early, on-time or late. Early and late deliveries are considered to be delivery process defects that contribute waste to the supply chain. Early deliveries contribute to excess inventory holding costs; late deliveries contribute to production stoppage costs and loss of customer goodwill.

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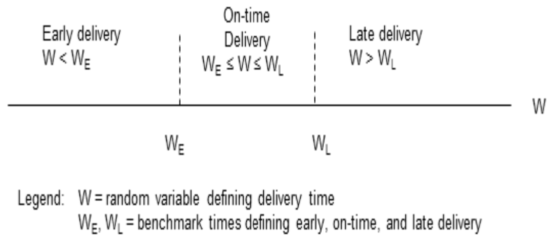

Fig. 1 Supply chain delivery window

This paper is organized as follows. In Section II, we present a summary of supply chain delivery window models that are found in the literature and identify parameterizations of delivery windows found in industry. Our conclusions and directions for future research are presented in Section III.

II. Supply Chain Delivery Models

Supply chain delivery performance models that use delivery windows have been contributed by several researchers. In this section we categorize these models according to the following two dimensions: i) type of model used (loss function versus Six-Sigma), and ii) type of random variable that is used to define the delivery time distribution (Gaussian versus non-Gaussian; continuous versus discrete). All delivery window models translate the probability of early and late deliveries into an expected cost of untimely (early and late) delivery. Loss function models use partial expectations of the probability density/probability mass function of the delivery time distribution to evaluate the expected cost of untimely delivery. Six-Sigma based models utilize statistical tools such as process capability indices, tolerancing and control charts to provide cost based metrics for evaluating delivery performance. For a gateway into the literature on these two different classes of supply chain delivery models the reader is referred to [6] for loss function based models and [7] for Six-Sigma based models.

A. Review of Model Types

The literature on supply chain delivery performance models with delivery windows is categorized in Table I. Models are classified by the type of probability density/mass function used to define the delivery time distribution (Gaussian versus non-Gaussian; continuous versus discrete) and whether the model uses a loss function or Six-Sigma design. Examining Table I we note that 17 out of 38 of the models use the Gaussian probability density function (pdf) to model the delivery time distribution. Within this class of Gaussian models loss function based models are more prevalent than Six- Sigma based models.

TABLE I
CATEGORIZATION OF SUPPLY CHAIN DELIVERY MODELS

Structure of Delivery Performance Model	Type of Delivery Time Distribution	Form of Delivery Time Distribution and Model Citations
Loss Function	Continuous	Gaussian 2013: [8], [9] 2010: [10] 2009: [11], [25] 2008: [12],[13] 2006:[6],[15] 2005: [20] Laplace 2005: [20] Uniform 2012: [4],[29] 1999: [19] Triangular 1999: [19] Asymmetric Laplace 2012: [4] 2011: [21] 2008: [18] 2005: [20] Gamma 2011:[31] 2005: [20] Logistic 2012: [4] Truncated Gaussian 1999: [19] Exponential 2012: [4] Unspecified 2012: [30] 2011: [24]
	Discrete	Multinomial 2011: [21] 2010: [17] Empirical 2013: [16] 2007: [14]
Six Sigma	Continuous	Gaussian 2013: [23] 2010: [33] 2008: [27] 2007: [26] 2006: [7],[22],[32] Gamma 2008: [28]

As seen in Table I, the Gaussian is the most widely used pdf for defining the distribution of supply chain delivery times. An attractive feature of using the Gaussian to define the supply chain delivery time distribution is the fact that the Gaussian is reproductive under addition. When the activity times for the stages of the supply chain are independent and Gaussian distributed, the delivery time distribution (which is the sum of the stage activity times) is Gaussian with a mean equal to the sum of the stage mean activity times and a variance equal to the sum of the variances of the stage activity times. Using the Gaussian greatly simplifies the mathematical analysis to determine the form of the pdf governing the delivery time distribution. Also, give the ease of performing probability calculations using a Gaussian; the supporting numerical analyses to evaluate the probability and costs associated with delivery performance are greatly simplified.

However, using the Gaussian pdf to define the supply chain delivery distribution can be problematic. By definition the Gaussian is symmetric and mesokurtic. As demonstrated by the case study data of [16], [20] and the computer simulations of supply chains conducted by [14], the delivery time distribution is typically not symmetric and can be either leptokurtic or platykurtic in shape. Hence, densities such as the asymmetric Laplace or gamma may more accurately depict the true delivery time distribution in a supply chain since these densities can be parameterized to represent delivery time distributions that are symmetric or skewed as well as leptokurtic or platykurtic. Alternatively, given data on the delivery time distribution the true empirical probability mass function can be used to evaluate delivery performance as demonstrated in [14], [16].

There has been limited us of discrete probability mass functions in the modeling of supply chain delivery distributions. When available, the empirical distribution will provide exact results. In cases where the delivery time is recorded as an early or late deviation from the on-time portion of the delivery window, the multinomial probability mass function (pmf) has been demonstrated to accurately capture the underlying form of the delivery time distribution [17], [21].

Delivery models based on Six-Sigma concepts are, with the exception of [28], based on the Gaussian. Six-Sigma delivery models utilize the C_p, C_{pk} and S_{pk} process capability indices which are Gaussian based indices.

B. Review of Delivery Windows

A common feature to the supply chain delivery performance models found in Table I is the delivery window. As illustrated in Fig. 1, the delivery window defines whether a delivery to the final customer in the supply chain is considered to be either early, on-time or late. Delivery windows first appeared in the operational research models for vehicle routing and scheduling [34] and then became an integral component of analyzing delivery performance under the Just-In-Time production philosophy [35]. Table II contains a summary of delivery windows reported in industry case studies found in the literature. Examining Table II we note that delivery windows have been implemented across a diverse set of industries. The magnitude of the delivery windows vary from minutes to weeks.

III. SUMMARY

This paper has provided an up-to-date record of the literature on 38 supply chain delivery performance models. The models have been classified by their key attributes such as model type (loss function versus Six-Sigma) and form of pdf/pmf (Gaussian versus non-Gaussian; continuous versus discrete) used to model the supply chain delivery time distribution. A wide range of symmetric pdfs have been used such as the Gaussian, uniform, triangular, and Laplace. Densities capable of modeling skewed delivery time distributions such as gamma and asymmetric Laplace have also been used. Discrete delivery models based on the multinomial and empirical distributions have received less use than continuous distributions in both the loss function and Six-Sigma model types. Examples of delivery windows used in various industries have also been summarized.

TABLE II
INDUSTRY DELIVERY WINDOW DEFINITIONS

Delivery Window Definition	Industry	Reference
20 minutes	Cement	[36]
30 minutes early to 30 minutes late	Food distribution	[37]
45 minutes	Automotive assembly	[38]
2 hours	Automotive	[39]
2 hours	Package delivery	[40]
4 hours	Automotive	[41]
3 days	Chemical	[42]
3 days early to zero days late	Computer	[43]
Zero days early to four days late	Telecommunication	[44]
4 days early to zero days late	Machinery	[20]
5.1 days early to 1.8 days late	A survey across multiple industries	[45]
2 weeks early to zero days late	Semiconductor	[43]
Less than 2.9 weeks early; 3.0 to 4.9 weeks on-time; 5.0 weeks or more late	Plastics	[46]

This review supports our first two research objectives by providing in one paper a synthesis of supply chain delivery models. This single source consolidation of the literature may prove useful to academicians who are interested in continuing current research programs or establishing new research in supply chain delivery performance and to practitioners who may be interested in evaluating delivery performance using a formal supply chain delivery model.

There are several aspects of the current body of literature that can be investigated. First, none of the models consider environmental aspects in their formulations. The delivery process is a critical part of the “last mile problem” in supply chains. This aspect of the supply chain contributes heavily to the carbon load that is placed on the environment. Integrating green and sustainable practices into the current portfolio of supply chain delivery models may help to reduce the carbon burden placed on the environment.

Second, models for evaluating supply chain delivery performance fail to take into account production and distribution capacity. Since the vast majority of deliveries are made by motor carrier, the integration of transportation freight rates in the models could provide a more accurate representation of the overall delivery process.

Third, all models with the exception of [9] assume a serial supply chain where the activity times of each stage are independent. There is a need for additional research on modeling stage dependent supply chains for both serial and multi-echelon supply chain configurations.

Lastly, more research is needed on modeling the continuous improvement of supply chain delivery performance. Within the current set of models, delivery improvement is introduced by reducing the variance of the delivery time distribution. For a fixed delivery mean and delivery window, reducing the variance of the delivery time distribution shifts more probability mass into the on-time portion of the delivery window thereby reducing the cost of early and late delivery. A limitation to these models is that the reduction in delivery variance occurs only at one point in time when in reality a continuous improvement program to improve the delivery process typically requires a planning horizon of several time periods in length with defined performance milestones. These gaps provide research opportunities for the advancement of supply chain delivery performance models along the dimensions production and transportation capacity, green and sustainable practices and continuous improvement.

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