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Investigating the effects of lead-time uncertainties and safety stocks on logistical performance in a border-crossing JIT supply chain

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ABSTRACT

We study a dual delivery risk problem that firms inside the free trade zones (FTZ) along the US-Mexico border (i.e., maquiladoras) often face in their daily operations. It is commonly observed that maquiladoras' suppliers keep buffer inventories of components in a 3rd party logistics (3PL) warehouse on the US side of border. Maquiladoras will "call-off" the components when they are needed for production runs, often multiple times a day. Each call-off shipment is an international shipment that is involved with export/import procedures and is subject to customs inspection, which often causes delays. Such delivery uncertainty, combined with the 3PL replenishment uncertainty, makes just-in-time (JIT) operations a challenging task for maquiladoras. In this study, we examine how a firm's logistical performance can be affected by multiple transportation risks and multi-locational buffer inventory strategies in a border-crossing JIT supply chain. Our results show that a firm's service level is more affected by the border-crossing uncertainty, whereas a firm's order lead-time performance is predominantly attributed to the 3PL replenishment risk.

1. Introduction

Free Trade Zones (FTZ) inside Mexico along the United States (US)-Mexico border have been one of the most important manufacturing bases for the US market for decades. Currently, there are close to 4000 manufacturing plants, i.e., maquiladora, employing more than one million workers producing everything from auto parts to cellular phones to personal computers to jeans in the FTZ. FTZ provides firms a production environment that is low-cost, tariff free, and duty free within proximity of the world's largest consumer market. Firms typically import raw materials and parts from different countries into FTZ for assembly via the US, and then export the assembled/manufactured products to a designated country, predominantly, the US.

The US-Mexico border makes firms' supply chains and logistics structure a unique and interesting case. Maquiladoras, like any manufacturing firm, well understand the importance of avoiding high levels of inventory in any form. In fact, many maquiladoras strive to practice just-in-time (JIT) operations in order to lower their production costs (Lawrence & Hottenstein, 1995). Therefore, it is widely observed that maquiladoras request their suppliers to store buffer inventory of components in a 3rd party logistics (3PL) warehouse nearby; manufacturers will then "call-off" the components needed for production runs on a daily basis. It is commonly observed that maquiladoras make multiple call-off deliveries on each working day.

However, instead of using those in Mexico, maquiladoras and their suppliers often choose to use 3PL warehouses on the US side of border. It has been observed that 3PL does not appear to be as common practice in Mexico as it is US, European countries, and some Latin American countries (Arroyo, Gayton, & De Boer, 2006). Drake and Rojo (2008) found that governmental obstacles and logistics infrastructure are the two most critical factors preventing 3PL industry to thrive and prosper in Mexico. Another consistent challenge is the Mexican workforce; many logistics firms in Mexico experience high employee turnover and difficulty in recruiting and retaining quality employees (Fawcett, Taylor, & Smith, 1995). In contrast, 3PL service providers in the US have been remarkably successful in recent years and are capable of providing customers with complete, integrative services including warehousing, inventory management, freight forwarding, importation and exportation, and customs clearance. Specifically, it is not uncommon that these US 3PL service providers can established electronic data linkage (EDI) with their customers, so that customers can place orders and monitor inventory levels and transactions electronically, which is attractive to many manufacturing firms inside FTZs. Consequently, hiring 3PL service providers located on the US side of border is

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extremely popular among maquiladoras and their suppliers.

Nonetheless, using US 3PL service providers means that each call-off made by a maquiladora is involved with "border crossing" and thus, each shipment is an international shipment. Therefore, such call-off deliveries will have to go through the export/import procedures and are subject to customs inspection. While the distance travelled may be well below 20 miles, a call-off delivery can take somewhere between four to six hours due to the increasing freight traffic between US and Mexico that often causes long waiting lines on many international bridges. And if a shipment is held by customs for inspection (i.e., getting a 'red light' at customs), it may take hours or, in some extreme cases, even more than a day before a truck can be released. This greatly increases the level of call-off uncertainty and can seriously affect a firm's production and delivery schedules, especially for firms that practice JIT and carry very little component inventories. Not surprisingly, border crossing and customs clearance have a high impact on the logistics performance index rating of a country (World Bank, 2016).

In this research, we study a "dual" delivery risk problem that firms inside FTZs (i.e., maquiladoras) commonly face in their daily operations. This problem was observed in the course of the association the authors had with the Wistron Corporation, a Taiwan-based company that develops high-technology (high-tech) products such as PCs, servers and storage systems, LCD TVs, and networking and communication systems. Wistron Corporation employs 20,000 workers worldwide and has a manufacturing facility, Wistron Mexico S.A. de C.V., inside the FTZ located in Ciudad Juárez, Chihuahua, Mexico. Having very little margin, Wistron implements JIT systems in order to lower inventory levels, and strives to deliver on time, which is extremely important to its customers.

To practice JIT, Wistron has the majority of its suppliers keeping buffer inventories in several 3PL warehouses located in El Paso, TX. Suppliers typically keep two to four weeks of inventory in these 3PL warehouses. Wistron makes daily call-offs to fulfill production needs that are based on customer's orders. When the inventory level of a component is down to the reorder point, the supplier will be responsible for replenishing the inventory by sending another shipment of components, typically, from Asia, which may take one to four weeks, depending on the means of transportation. Sometimes replenishment shipments may be delayed due to various factors such as lack of capacity, transportation delays, extreme weather, and customs issues, which may seriously affect Wistron's plans to produce and deliver on time. The call-off delivery uncertainty due to border crossing further compounds the effect of delivery risks on achieving high service levels. Increasing on-hand inventory level appears to be an effective means of mitigating the impact of replenishment and call-off risks on Wistron's service level. However, carrying inventory on hand means more space required and higher operational costs, which is in conflict with the JIT philosophy.

Motivated by the dilemma that Wistron and many other maquiladoras are facing, this research investigates the effects of dual transportation risks and multilocational inventory policies on firms' performance in a JIT environment involved with border crossing. Specifically, we examine how a firm's service level can be affected by replenishment lead-time uncertainty, call-off lead-time uncertainty, buffer inventory level in the 3PL warehouses, and on-hand safety stock. Importantly, the call-off risk can be observed not only in "international" deliveries along the US-Mexico border, but also in domestic deliveries in many large cities such as Los Angeles and Houston where congestions on highways is becoming a norm on any typical working day. Call-offs deliveries, or last-mile deliveries, in such big cities are extremely uncertain due to heavy traffic that causes frequent delays.

The following sections review literature related to key factors that affect service performance in a JIT setting, develop the research hypotheses, describe the research methods, analyzes the data, discuss the findings and managerial implications, and summarize this research and point to future research directions.

2. Literature review

In past decades, the subject of "supply chain risk" has received tremendous amount of attention both in academia and in industry due to the recent trend of globalization and outsourcing that typically lead to a widely dispersed supply chain structure across different countries and continents. Besides the common issues of supply and/or capacity shortages, many disasters from earthquake to extreme weather to strikes have also created numerous problems for the supply chains of global companies (Sodhi & Tang, 2012). To understand and manage supply chain risk better, many typologies of sources of supply chain risks have been proposed (Chopra & Sodhi, 2004; Christopher & Peck, 2004; Ellis, Shockley, & Henry, 2011; Manuj & Mentzer, 2008; Rao & Goldsby, 2009). For instance, Chopra and Sodhi (2004) categorized various risk types into nine sources: disruptions, delays, system, forecast, intellectual property, procurement, receivables, inventory, and capacity. Each of these sources is further classified from three perspectives: supplier-related, internal, and demand-related. Wagner and Bode (2008) divided supply chain risk sources into five distinct classes: demand side, supply side, infrastructure, catastrophic and regulatory/ legal/ bureaucratic. It is also common that various risk sources are classified into three categories: supply-side risk, internal or operational, risk and demand-side risk (Manuj & Mentzer, 2008; Talluri, Kull, Yildiz, & Yoon, 2013).

In the same vein, researchers also investigated strategies that can effectively mitigate various types of supply chain risks (Chopra & Sodhi, 2004; Craighead, Blackhurst, Rungtusanatham, & Handfield, 2007; Kull & Closs, 2008; Manuj & Mentzer, 2008; Talluri et al., 2013; Wagner & Bode, 2008; Zsidisin & Ellram, 2003). For instance, Chopra and Sodhi (2004) propose the following strategies for risk mitigation: increase capacity, acquire redundant suppliers, increase responsiveness, increase inventory, increase flexibility, pool or aggregate demand, and increase capability. Manuj & Mentzer (2008) propose a five-step risk management framework that may help firms to effectively identify mitigating strategies for risks: risk identification, risk assessment and evaluation, selection of appropriate risk management strategies, implementation of supply chain risk management strategy(s), mitigation of supply chain risks. Christopher and Lee (2004) argue that improving visibility is key to successful mitigation strategies for different types of supply chain risks. Wagner and Bode (2008) advocate that firms should allocate scarce resources to mitigating demand and supply risks in order to enhance firms' performance. Talluri et al. (2013) adopted the data envelopment analysis (DEA) technique to analyze and rank alternative mitigation strategies. They demonstrated that the more efficient strategies focus on flexibility rather than on redundancy for supply chain failures. Our research investigates a subset of risk sources and mitigation strategies that are most closely related to the problems that our focal company encounters on its day-to-day operations.

Delivery/lead-time uncertainty and its impact on firms' performance has been extensively studied in the literature (Hariharan & Zipkin, 1995; Kouvelis & Li, 2008; Lau, 1989; Ray, Li, & Song, 2005; Schwarz & Weng, 1999; Speh & Wagenheim, 1978; Wu, Kazaz, Webster, & Yang, 2012). It is commonly concluded, both analytically and empirically, that a higher level of delivery uncertainty will lead to a higher level of inventory or lot-size and has a negative impact on performance (Bashyam & Fu, 1998; Hill & Vollmann, 1986; Karmarkar, 1994; Kouvelis & Li, 2008; Weng & McClurg, 2003; Wu et al., 2012). Schwarz and Weng (1999) conducted a comprehensive research that examines lead-time related design issues in a multiple-echelon JIT supply chain. They demonstrated how manufacturers can reduce the variance of "end-of-cycle" inventory by adjusting their allocation schemes. They also argue that supply chain design should incorporate both lead-time uncertainty and inventory holding costs in achieving the level of service desired.

The classic mitigation strategies against delivery uncertainty are safety stock and safety lead-time (Hill & Vollmann, 1986; Natarajan &

Goyal, 1994). Additionally, more accurate forecasting (Karmarkar, 1994), increased information sharing (Hariharan & Zipkin, 1995), increased flexibility (Kouvelis & Li, 2008; Tang & Tomlin, 2006) and responsiveness (Chopra and Sodhi (2004)), and higher level of supply chain integration (Sanchez-Rodriguez, Potter, & Naim, 2010) are also shown to effectively mitigating the effects of delivery uncertainties.

Research regarding safety stock policies in non-JIT environment is rich. Numerous factors have been found affecting safety stock levels. Examples of these factors are lead-time uncertainty (Chopra, Reinhardt, & Data, 2004; Tallon, 1993; Zinn & Marmorstein, 1990), supply or demand uncertainty (Benton, 1991; Hsu & El-Najdawi, 1991; Zinn & Marmorstein, 1990) or both (Rawls & Turnquist, 2010), forecast error (Zinn & Marmorstein, 1990), lotsizing (Benton, 1991; Hsu & El-Najdawi, 1991), replenishment frequency (Benton, 1991; Waller, Johnson, & Davis, 1999), commonality (Benton & Krajewski, 1990; Collier, 1982), and resource utilization (Ezingeard & Race, 1995). In contrast, research regarding "on-hand" safety stock in a JIT environment is relatively scarce (Chapman, 1992; Natarajan & Goyal, 1994; Schwarz & Weng, 1999). JIT views on-hand inventory as a type of waste. Thus, from a manufacturer's standpoint, it is the supplier's responsibility for preparing component safety stock. In general, components or raw materials are scheduled for delivery only hours before they are needed for production (Hill & Vollmann, 1986). With such tight control of schedules, even a traffic jam can easily cause delay, which exposes production floor to the risk of stock-outs. Therefore, certain level of on-hand safety stock is still necessary even in a JIT environment in order to cope with last-mile delivery uncertainties (Chapman, 1992; Natarajan & Goyal, 1994).

While research has investigated the impact of delivery uncertainty (or risk) on firm performance and the mitigating effect of buffer inventory (Hariharan & Zipkin, 1995; Hill & Vollmann, 1986; Schwarz & Weng, 1999; Chung, Talluri, & Narasimhan, 2012; Kouvelis & Li, 2008; Ray et al., 2005; Wu et al., 2012), to the best of our knowledge, extant work on the effects of multiple delivery uncertainties and safety stocks in multiple locations on firms' performance in a "border-crossing JIT" environment in scant. As Stank and Crum (1997) point out, even maquiladoras in a JIT environment in fact carry extra on-hand safety stock to counteract disruptions due to border crossings. The same is confirmed for border-crossings between the US and Canada even after the NAFTA agreement (Taylor, Robideaux, & Jackson, 2004). Besides the well-understood lead-time uncertainty of replenishment, we argue that call-off delivery or last-mile delivery may also be subject to high level of uncertainty and can seriously affect firms' production schedule and on-time delivery performance. On one hand, when both replenishment uncertainty and call-off delivery uncertainty exist in a JIT supply chain, it is not clear which source of delivery uncertainty plays a bigger, more critical role in adversely impacting performance in the presence of a border. On the other hand, carrying buffer inventory or safety stock in the 3PL warehouse and in the manufacturing plant are effective strategies to mitigate the impact of these two types of delivery uncertainties. However, it is not clear which type of buffer stock is more effective in mitigating delivery risk in the environment of our interest. Our research seeks to address these issues and fill the gap in the literature.

3. Development of experimental hypotheses

We considered the types of risk resources proposed by Chopra and Sodhi (2004) and discussed each of them comprehensively with Wistron's managers. In the context of day-to-day operations, we decided to focus on the two sources of risk that most seriously affect Wiston's daily JIT performances in our model; they are multiple delivery uncertainties and multi-locational buffer inventories. Wistron's managers also felt that both capacity risk and forecast risk are somewhat important to achieving their JIT goals, but, in general, their impact is not as significant as delivery uncertainties and buffer inventory levels. Therefore, we treat capacity and forecast risks as control variables in our model. Other sources of risk such as internal system (breakdown), intellectual property, procurement, and receivables mentioned by Chopra and Sodhi (2004) occur relatively less frequently in Wistron's daily operations. Therefore, they are not considered in this study.

Many different measures have been used to assess firm performance in different areas. Specifically, order fill rate, delivery dependability and speed, quick response, on-time delivery, and order accuracy are often adopted for evaluating firms' logistics performance (Eroglu & Hofer, 2011; Gligor & Holcomb, 2012; Smith & Mentzer, 2010; Wagner & Bode, 2008). We consider two metrics that are widely used in the literature and that are highly emphasized by Wistron: service level and order lead-time (Lawrence & Hottenstein, 1995; Manuj & Mentzer, 2008; Talluri et al., 2013; Taylor, Fawcett, & Jackson, 2004; Wagner & Bode, 2008). Consistent with the literature, we define service level as the percentage of orders (units) that are produced without any delay (Schwarz & Weng, 1999; Stevenson, 2012; Talluri et al., 2013). Order lead-time is measured by the amount of time from when an order is being placed by the customer to the time when the order is completed (Miller, Saldanha, Hunt, & Mello, 2013; Stank, Goldsby, Vickery, & Savitskie, 2003; Wagner & Bode, 2008).

3.1. Delivery uncertainties

The impact of delivery uncertainty on firm performance is clear and straightforward. When the arrival time of a shipment is uncertain, a manufacturing firm will likely suffer from frequent changes in production schedules, resulting in higher production cost and lower customer satisfaction (Hill & Vollmann, 1986; Schwarz & Weng, 1999; Weng & McClurg, 2003; Kouvelis & Li, 2009; Talluri et al., 2013). Hill and Vollmann (1986) found that when reduction in delivery uncertainty is achieved, firms may enhance their response flexibility and reduce the need of high buffer stock, resulting in greater cost savings. Schwarz and Weng (1999) found that the payoff from reducing lead-time uncertainty is often as important, if not more important, than reducing demand uncertainty. However, reduction of delivery uncertainties are typically not controllable by manufacturing firms. Weng and McClurg (2003) show that a higher level of information sharing and coordination can effectively hedge against the effects caused by delivery uncertainties.

In this study, members of our focal supply chain are cooperative and coordinate with each other. Forecast and demand information are made available to all supply chain members so that the suppliers know when and how much inventory must be replenished from the 3PL warehouse. However, two sources of delivery uncertainties were thought to have a significant impact on JIT performance: the uncertainty associated with replenishment shipments from a supplier's site to a 3PL warehouse and the uncertainty associated with call-off, or last-mile deliveries, from the 3PL warehouse to the manufacturing plant. On the one hand, when the arrival of replenishment shipments is highly unpredictable, firms more likely will run out of buffer stock and thus, may have to change their production schedule frequently, causing longer order lead-time and lower service level (Chopra & Sodhi, 2004; Sanchez-Rodriguez et al., 2010). On the other hand, when a call-off delivery is made, it may not arrive at the manufacturing plant on time due to delays caused by border crossing or traffic congestion. This will also cause the manufacturing plant to have to postpone its production schedule and may potentially decommit to the promised delivery deadlines of its customers. These two sources of delivery uncertainties are independent of each other, but they share similar effects on firm performance in a JIT environment.

H1A. In a JIT system, replenishment lead-time uncertainty has a negative effect on the manufacturer's service level.

H1B. In a JIT system, call-off lead-time uncertainty has a negative effect on the manufacturer's service level.

H1C. In a JIT system, replenishment lead-time uncertainty has a negative effect on the manufacturer's order lead-time performance.

H1D. In a JIT system, call-off lead-time uncertainty has a negative effect on the manufacturer's order lead-time performance.

3.2. Buffer stock: direct and moderating effects

One of the main functions of buffer stock is to smooth production schedules and increase the amount of demand that can be satisfied (Chopra & Meindl, 2010), leading to a higher service level (Hsu & El-Najdawi, 1991; Stevenson, 2012). Additionally, buffer stock is also one of the most commonly used mitigating strategies against delivery uncertainty and demand uncertainty (Hill & Vollmann, 1986; Natarajan & Goyal, 1994; Kouvelis & Li, 2008). With buffer stock, effects of delivery and demand uncertainties are minimized and firms' delivery performance is enhanced. However, higher inventory levels result in higher costs and lower financial performance (Chopra & Sodhi, 2004). To minimize inventory risk and to take advantage of inventory benefits in a JIT system, a common practice is to have suppliers maintain buffer inventory in a 3PL warehouse near the manufacturing plants. The manufacturing plants will pull, or call-off, small lot-size of components moments before a production run is scheduled to start (Natarajan & Goyal, 1994). By doing so, a manufacturing firm can still practice the JIT system even when the suppliers are far away from the manufacturer.

However, deliveries of components from a nearby 3PL warehouse to a manufacturing plant has a certain lead-time, which can also be uncertain depending on the distance, traffic conditions, and routing. When such a call-off lead-time is uncertain, it may be necessary for a manufacturing plant to carry safety stock on-hand (on-site) in order to mitigate the effects of call-off delivery uncertainty, even if it is practicing a JIT system. Without on-hand safety stock, firms will be frequently exposed to stock-outs (Natarajan & Goyal, 1994), resulting in delay of shipments and lower customer satisfaction. Therefore, while efforts are undertaken to identify the sources of supply and demand uncertainties and eliminate them (Hill & Vollmann, 1986), on-hand safety stocks are still necessary in a JIT environment (Natarajan & Goyal, 1994; Schwarz & Weng, 1999). On-hand safety stock functions similarly to buffer inventory stocked in a 3PL warehouse, except that the former is used to hedge against call-off or last-mile delivery uncertainty while the latter is used to mitigate the effect of replenishment uncertainties. They both allow firms to achieve higher service level and reduce the order lead-time for customers. In addition, they both can mitigate the effects associated with delivery uncertainties.

H2A. In a JIT system, 3PL buffer stock has a positive effect on the manufacturer's service level.

H2B. In a JIT system, on-hand safety stock has a positive effect on the manufacturer's service level.

H2C. In a JIT system, 3PL buffer stock has a positive effect on the manufacturer's order lead-time performance.

H2D. In a JIT system, on-hand safety stock has a positive effect on the manufacturer's order lead-time performance.

H3A. In a JIT system, 3PL buffer stock positively moderates the effect of replenishment lead-time uncertainty on a manufacturer's service level.

H3B. In a JIT system, on-hand safety stock positively moderates the effect of call-off lead-time uncertainty on a manufacturer's service level.

H3C. In a JIT system, 3PL buffer stock positively moderates the effect of replenishment lead-time uncertainty on a manufacturer's order lead-time performance.

H3D. In a JIT system, on-hand safety stock positively moderates the effect of call-off lead-time uncertainty on a manufacturer's order lead-time performance.

3.3. Stronger effects

While the effects of replenishment shipment uncertainty and call-off delivery uncertainty on firm performance are commonly recognized, it is not clear whether the magnitudes of such effects are similar or significantly different when different performance measures are adopted. We argue that, in a JIT environment, the effect of call-off delivery uncertainty is more significant than that of replenishment uncertainty on service level in a JIT system. In contrast, the effect of replenishment uncertainty is more significant than that of call-off delivery uncertainty on firm's order lead-time performance in a JIT system.

As mentioned previously, service level is typically measured by the percentage of orders or units that are produced and shipped to customers on time (Schwarz & Weng, 1999; Stevenson, 2012; Talluri et al., 2013). On the one hand, in a JIT system, the manufacturing firm calls-off for component delivery moments before they are needed for production (Hill & Vollmann, 1986). When a call-off delivery is delayed due to border crossing or heavy traffic conditions, the manufacturing firm will suffer from uncertain component arrival time and likely will have to postpone its planned production schedule. This can frequently affect the manufacturing firm's performance in service level as call-off deliveries are conducted on a daily basis and in many cases, a manufacturing firm may make multiple call-offs each day (Natarajan & Goyal, 1994).

On the other hand, replenishments are typically arranged once or twice a month in practice, depending on distance travelled, and reorder point and buffer stock policies. When a replenishment is delayed, the manufacturing plant will be exposed to serious stock-out risk. However, it happens relatively less frequently and thus, it has a lesser impact on firm's on-time delivery performance. Specifically, the manufacturing firm's on-time production and delivery schedules will be safeguarded against the uncertainty associated with replenishments so long as there is buffer stock in the 3PL warehouse. Given this,

H4A. In a JIT system, the call-off lead-time uncertainty has a greater impact on a manufacturer's service level than the replenishment lead-time uncertainty.

However, when considering manufacturing firm's order lead-time performance, we argue that the replenishment lead-time uncertainty plays a more critical role than the call-off lead-time uncertainty. Order lead-time is measured by the amount of time from the customer places an order to the time that order is completed and is out for delivery. In general, higher value of order lead-time indicates a lower level of performance. Although lead-time uncertainty associated with call-off deliveries can seriously affect the manufacturing plant's production schedules, such lead-time uncertainty is subject to several hours of delays in daily operations; rarely do call-off delays exceed the course of one day. In contrast, delays in replenishment can easily be several days or even more than one week. Such delays can significantly increase the amount of time measured by order lead-time and thus, they present a more serious threat to the manufacturing firm's order lead-time performance (see Fig. 1).

H4B. In a JIT system, the replenishment lead-time uncertainty has a greater impact on a manufacturer's order lead-time performance than the call-off lead-time uncertainty.

4. Research methods

Simulation has long been used by various researchers in such areas as logistics, operations, and supply chain management (Bowersox & Closs, 1989; Fallon & Browne, 1988; Holweg & Bicheno, 2002; Savsar, 1997; Talluri et al., 2013). It has the ability to model complicated

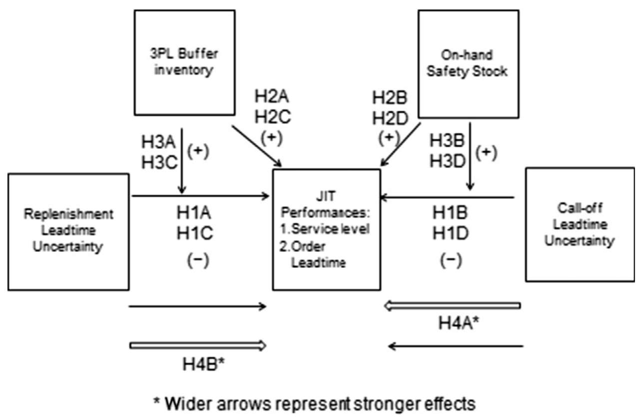

Fig. 1. The research model.

supply chain systems and test responses on key factors to different supply chain phenomena in a laboratory environment (Kull & Closs, 2008). Interestingly, simulation has yet to be used widely in research focusing on supply chain risk (Melnyk, Rodrigues, & Ragatz, 2009), although it is considered an efficient and effective tool for modeling and analyzing supply chain risk (Kull & Closs, 2008; Zsidisin, Ellram, Carter, & Cavinato, 2004). We adopt simulation as the tool to investigate the research problems discussed in earlier sections. Results generated by the simulation model are then analyzed and tested by the ordinary least squares (OLS) hierarchical moderated regression models.

4.1. Model description

We consider a supply chain that consists of a supplier, a 3PL warehouse, a manufacturer, and a customer (See Fig. 2). Demand is uncertain. The customer provides the manufacturer with a 13-week forecast on a weekly basis and releases firm orders to the manufacturer on a daily basis. The supplier is located in a foreign country and keeps buffer stock in the 3PL warehouse near the manufacturer for JIT service. However, there exists a border between the 3PL warehouse and the manufacturing plant. Therefore, each call-off delivery is an international shipment that involves exportation and importation and is subject to customs inspection. To reduce the complexity, we consider only one product and one component in the simulation model.

4.2. The simulation model

The simulation model consists of three major operational processes: order fulfillment process, call-off process, and replenishment process (See Fig. 3). We discuss these processes in greater detail below.

(1) Order fulfillment process: The customer releases orders daily to the manufacturer in this JIT system. The manufacturer will then call-off the materials required from the 3PL warehouse and schedule production runs shortly after an order is received. The manufacturer carries some safety stock on hand that allows them to start a production run promptly. The call-off materials are generally required in order to completely fulfill customer's orders. Once production is completed, products will be delivered to the final destination. To reduce the complexity, we assume that the customer will release the orders at the same time on each working day. We also assume that the manufacturer operates 24 h a day. When production of the focal product is interrupted due to shortage or late arrival of components, the manufacturer can immediately resume the production once the components are received.

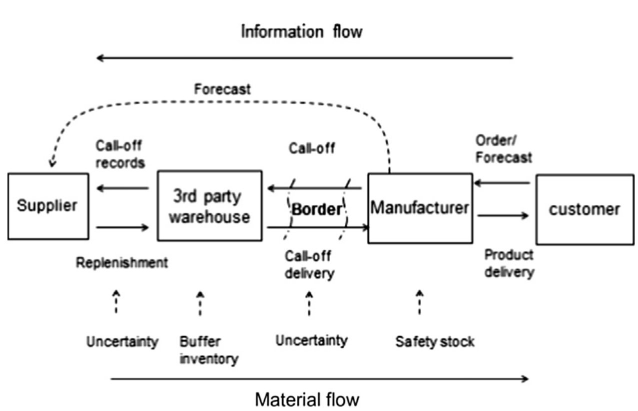

Fig. 2. The border-crossing just-in-time supply chain.

(2) Call-off process: When the manufacturer calls-off the component, the call-off quantity includes the units needed based on customer's order and the required on-hand safety stock less the safety stock that is already on hand. Therefore, after an order is fulfilled, there will be safety stock left for the next order. A call-off delivery will be considered delayed if the shipment arrives after the on-hand safety stock has been completely consumed. When there is component shortage in the 3PL warehouse, the manufacturer will postpone the production schedule and the entire order is considered delayed.

(3) Replenishment process: The customer provides a 13-week forecast to the manufacturer on a weekly basis. Based on the demand forecast from its customer, the manufacturer also provides a 13-week component forecast to its supplier using material requirement planning (MRP). The supplier and manufacturer mutually agree upon a re-order point (ROP) and buffer inventory level, based on which the supplier replenishes buffer stock in the 3PL warehouse when inventory level reaches ROP. Replenishment can be delayed due to supplier's lack of capacity and/or transportation lead-time uncertainty.

4.3. Experimental factors

In order to obtain data and assess the hypothesized relationships, we include in the simulation model five factors that are directly and/or indirectly affecting the manufacturing firm's performance relating to service level and on-time delivery performance. Each factor has somewhere between two to four levels that are set in accordance with Wistron's operational experience. The relevant factors and experimental setting are described below and summarized in Table 1.

(1) 3PL buffer stock: In our model, we adopt weeks-of-supply as the buffer stock levels in the 3PL warehouse. Specifically, we set four levels of buffer stock in the 3PL warehouse in our experiments: two weeks, three weeks, four weeks, and five weeks of buffer stock, representing low to high buffer inventory levels. Each week, the specified weeks-of-supply inventory levels will be decided based on the 13-week forecast released by the manufacturer. Similarly, the ROP is set at two weeks of inventory in all experiments.

(2) On-hand safety stock: Although the manufacturer intends to practice a JIT production system, call-off deliveries involved with border-crossing force the manufacturer to carry some safety stock on-hand in order to start product runs promptly once receiving an order from its customer. In our experiments, the on-hand safety stock is set to 2 h, 4 h, 7 h, and 10 h of production based on the hourly output rate. Without loss of generality, we set the output rate at 60 units per hour.

(3) Replenishment lead-time: The amount of time from the point the need for replenishment is observed to the point the shipment arrives in 3PL is referred to as replacement lead-time. In general, carriers are able to provide the shippers with an estimated lead-time. However, shipments can be delayed due to such problems as weather conditions, traffic congestion, delay at airports, customs inspections, missing documents, etc. According to Wistron, delays

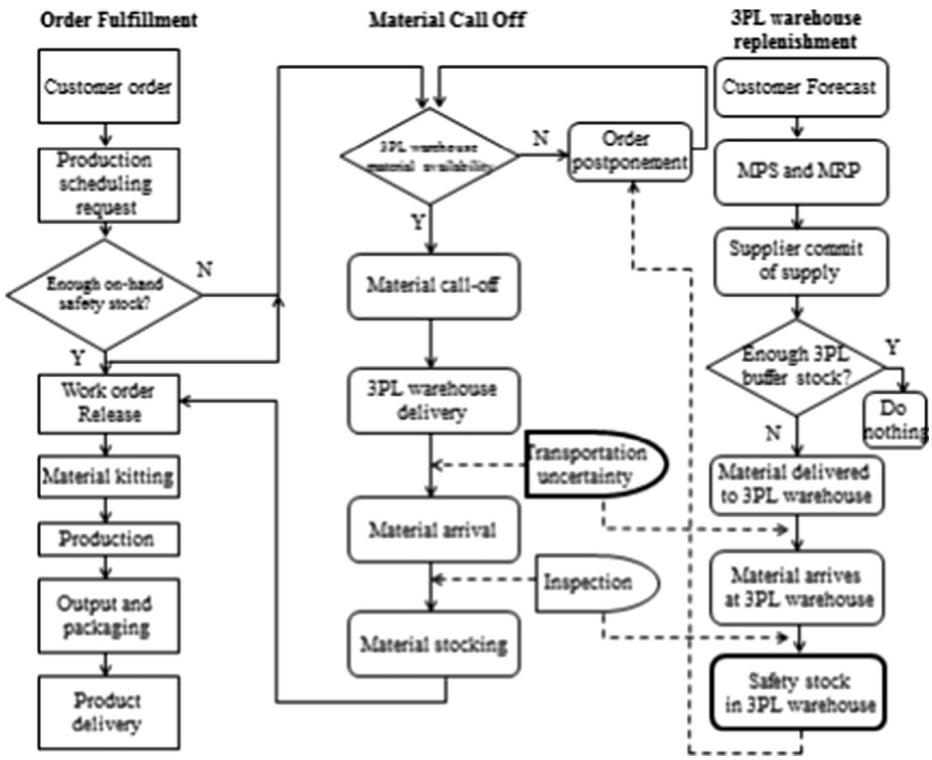

Fig. 3. The simulation model.

Table 1
Experiment design.

Factors	Levels
3PL buffer stock	2 weeks of supply
	3 weeks of supply
	4 weeks of supply
	5 weeks of supply
On-hand safety stock	2 h of supply
	4 h of supply
	7 h of supply
	10 h of supply
Replenishment leadtime (days)	TRIA (5, 7, 9)
	TRIA (5, 7, 14)
	TRIA (5, 7, 21)
Call-off leadtime (hours)	Green 90% / Red 10%
Green = TRIA(2, 3, 4)/Red = TRIA (6, 8, 10)	Green 80%/Red 20%
	Green 70%/Red 30%
Capacity risk	5%
	30%

due to missing shipments, mistaken materials, or pilferages happen relatively less frequently and thus, they are not considered in our simulation models. In other words, we assume that materials shipped will eventually arrive in the 3PL warehouse. Since the supplier is located in a foreign country, the replenishment shipments typically take about one week, more or less, with a combination of land and air transportation. We adopt the triangular distribution, TRIA (5, 7, 9), in units of days, for transportation lead-time distribution without delays. In contrast, two other triangular distributions, TRIA (5, 7, 14) and TRIA (5, 7, 21), are used for replenishments suffering more frequently from moderate and serious delays, respectively.

(4) Call-off lead-time: Although the 3PL warehouse is within close proximity to the manufacturer's plant, waiting time on an international bridge may be long. Each call-off delivery will hit either a green light or a red light at customs when crossing the border. When hitting a green light, the customer will release a truck as long as all required documents are available and prepared properly. However, when hitting a red light, a truck is subject to a thorough inspection, which may take a few hours. Similarly, we adopt a triangular distribution, TRIA (2, 3, 4), in units of hours, for the call-off deliver lead-time distribution without delays. We use TRIA (6, 8, 10) for the lead-time distribution representing delays due to custom inspection or long waiting time on the bridge. We set three levels of probability for trucks hitting a red light: 10%, 20%, and 30%.

(5) Capacity risk: We assume that when supplier's capacity is tight, the production and replenishment will be delayed for one week. We set two levels of opportunities, 5% and 30%, to represent low and high capacity risk, respectively. Although in some occasions supplier's lack of capacity can take a longer time to recover or even can never be recovered, such problems rarely occurred at Wistron due to its releasing a 13-week forecast to the supplier on a weekly basis. Therefore, such extreme cases are not considered in our simulation experiments.

4.4. Simulation formulation and validation

The simulation model was programmed on Arena V.7.01 by Rockwell Software (Kelton, Sandowski, & Sturrock, 2004). Arena is a dynamic software tool that combines graphical templates with analysis modules and that allows ease of use and creation of a variety of simulation models. Arena is also one of the best contemporary simulation tools that can be a simulator at the highest level of abstraction and still handle the fine detail at the lowest level of abstraction (Baibak, Williams, & Morrison, 1996). In particular, Arena has been used in manufacturing, logistics, supply chain management applications (Potter, Yang, & Lalwani, 2007).

The random number generator adopted by Arena 7.01 is called "combined multiple recursive generator" (CMRG). CMRG starts up two separate recursions and then combines them into one. The streams of random numbers will take a most up-to-date computer years to exhaust. In addition, in each replication, CMRG will automatically move to the beginning of the next sub-stream of random numbers, which is nonoverlapped with any other sub-streams of random numbers. Such multiple streams can be interpreted as "independent" Random Number Generators (RGN) (L'Ecuyer, Simard, Chen, & Kelton, 2002) and possesses extremely strong statistically properties (Kelton et al., 2004).

The initial condition, warm-up length, and number of replications are critical to the success of a simulation model (Kelton et al., 2004). The beginning buffer stock and on-hand safety stock were carefully selected in the simulation model in order to reflect reality. Thirteen-week forecasts and daily orders were generated by a uniform distribution with a range that resembles Wistron's forecast and demand patterns. Each simulation run was warmed up for 100 days (Talluri et al., 2013) and then was run for 104 weeks (i.e., two years). Since the delays of both the replenishments and the call-off deliveries are quite common, a run length of two years would allow us to defect the effects of interest and investigate the significance of such effects. The combination of all factor levels described in the previous section results in a $3 \times 3 \times 4 \times 4 \times 2$ factorial design. Vaghefi and Sarhangian (2009) adopted 10 replications in their simulation model to test the statistical significance between their results and those of previous work. Egilmez, Süer, and Huang (2012) also chose 10 replications in order for their simulation model to reach a steady state. Following Kelton's (2004) procedure, Talluri et al. (2013) determined 10 replications to be appropriate for at most a 1% relative error among all the outcome variables. Grounded in literature, we also adopted 10 replications in each scenario, creating a total of 2880 observations in the simulation experiments.

5. Experimental data analyses and results

We adopted the ordinary least squares hierarchical moderated regression models in order to test the hypotheses described in Section 3. The dependent variables are service level and order lead-time. The independent variables are replenishment (lead-time) risk, call-off (lead-time) risk, 3PL buffer stock, and the on-hand safety stock. The control variables are capacity risk and forecast error percentage.

5.1. Data analyses

The correlations among all key factors and the dependent variables are shown in Table 2. Basically, the signs of the correlations between the dependent and independent variables are all as expected except for the order lead-time and the on-hand safety stock. Although the sign of correlation between these two variables is positive, the correlation is extremely small and it is not significant.

However, significant correlations among certain key factors can be observed. To ease the concern of multicollinearity, focal variables included in the multiple regression models were all mean-centered. Additionally, we examined the tolerance and variance inflation factors (VIF) in order to detect potential multicollinearity (Hair, Anderson, Tatham, & Black, 2010). Tolerance is the amount of variability of the selected independent variable not explained by other independent variables, and VIF is the reciprocal of tolerance. Thus, a small tolerance value, or equivalently, a large VIF value, indicates a high degree of multicollinearity. A common cutoff threshold of tolerance value is 0.1, which corresponds to a VIF value of 10 (Hair et al., 2010). The lowest tolerance value of our independent variables in the two models is 0.74, or a VIF value of 1.35. This indicates that there does not exist any strong effect of multicollinearity in our multiple regression models.

In order to decide whether our simulation data was appropriate for the regression technique, we also examined the normality of error terms from the multiple regression models by utilizing the Kolmogorov-Smirnov test. The testing results were insignificant and the values fell along the diagonal with no substantial or systematic departure. Thus, we concluded that our data showed no sign of violating the normality assumption in the multiple regression models.

5.2. Results and discussion

Two separate hierarchical moderated regression models were used to test the hypotheses developed in the paper.

5.2.1. Effects on service level

Table 3 summaries the results of the hierarchical multiple regression model with service level as the dependent variable. As expected, the two lead-time risks and the two types of buffer stocks all have significant, negative effects on firm's service level. These direct effects alone account for 83.7% of the total variations. Therefore, hypotheses H1A, H1B, H2A, and H2B are all supported. Moreover, the hypothesized moderating effects described in H3A and H3B are also supported. The R^2 value of the full model is increased to 85.1%. We depict such positive moderating effects in Fig. 4(a) and (b). As one can observe, replenishment risk negatively affects the firm's service level. But 3PL buffer stock mitigates such negative effects; that is, the higher the 3PL buffer stock levels, the higher the service levels. This is consistent with the sign of the coefficient of the 3PL buffer stock in the multiple regression models.

Surprisingly, the effect of forecast risk, measured by forecast error percentage, on firm's service level is not significant. Prior studies considered forecast as one of the main sources of supply chain risk (Manuj & Mentzer, 2008; Talluri et al., 2013; Wagner & Bode, 2008). A common premise is that demand uncertainty and poor forecasting quality inevitably result in either excess inventories or shortages, resulting in lower firm performance. However, Chopra and Sodhi (2004) pointed out that that the effect of forecast risk can be lessened by buffer inventory levels when inventory holding cost is relatively low. Zhou and Benton (2007) also argued that higher level of information sharing can positively affect a firm's delivery performance. Our findings support these views. That is, in a JIT supply chain the effect of forecast error on a firm's service level can be mitigated by such practices as releasing forecast regularly and carrying buffer inventories in 3PL warehouses.

5.2.2. Effects on order lead-time

The results in the second model in which order lead-time is the performance measure are mixed. Note that a shorter lead-time

Table 2
Correlations among variables.

	Service level	Order leadtime	Capacity risk	Forecast error %	Replenish-ment risk	Call-off risk	3PL buffer	On-hand SS
Service level	1		−0.048**	−0.037*	−0.190**	−0.778**	0.177**	0.273**
Order leadtime		1	0.004	0.009	0.088**	0.002	−0.192**	0.004
Capacity risk			1	0.012	0.000	0.000	0.106**	0.005
Forecast error %				1	−0.011	0.001	−0.041*	−0.061**
Replenishment Risk					1	0.000	0.494**	0.004
Call-off risk						1	0.011	−0.005
3PL buffer							1	−0.049**
On-hand SS								1

Note: * $p < 0.1$; ** $p < 0.05$.

Table 3
Regression results: DV = Service level.

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	R Square
		B	Std. Error	Beta			
1	(Constant)	0.834	0.021		39.547	0.000	
	Capacity Risk	−0.033	0.013	−0.048	−2.558	0.011	
	Forecast Error %	−0.168	0.085	−0.037	−1.977	0.048	0.004
2	(Constant)	1.323	0.014		92.340	0.000	
	Capacity Risk	−0.033	0.008	−0.048	−4.285	0.000	
	Forecast Error %	−0.174	0.051	−0.038	−3.437	0.001	
	Replenishment Risk	−0.031	0.002	−0.190	−17.133	0.000	
	Call-off risk	−1.673	0.024	−0.778	−70.075	0.000	0.645
3	(Constant)	1.167	0.010		115.904	0.000	
	Capacity Risk	−0.065	0.005	−0.092	−12.168	0.000	
	Forecast Error %	−0.024	0.034	−0.005	−0.701	0.483	
	Replenishment Risk	−0.063	0.001	−0.390	−44.925	0.000	
	Call-off risk	−1.679	0.016	−0.781	−103.768	0.000	
	3PL Buffer	0.127	0.003	0.402	45.965	0.000	
	On-hand SS	0.042	0.001	0.291	38.485	0.000	0.837
4	(Constant)	1.312	0.013		99.705	0.000	
	Capacity Risk	−0.066	0.005	−0.094	−12.975	0.000	
	Forecast Error %	−0.018	0.033	−0.004	−0.552	0.581	
	Replenishment Risk	−0.119	0.005	−0.740	−25.728	0.000	
	Call-off risk	−1.938	0.030	−0.902	−65.189	0.000	
	3PL Buffer	0.045	0.007	0.143	6.526	0.000	
	On-hand SS	0.016	.003	0.111	5.787	0.000	
	Replenishment Risk × 3PL Buffer	0.057	0.004	0.537	12.739	0.000	
	Call-off Risk × Oh-SS	0.013	0.001	0.227	10.150	0.000	0.851

represents better performance. Therefore, the coefficients for the two control variables and the two risk-related variables are expected to be positive and the coefficients for the two inventory-related variables are expected to be negative. When examining the direct effects, we found that all coefficients of such effects have the expected signs, as indicated in Table 4. However, only the replenishment risk (H1C) has a significant effect on order lead-time ($p < 0.05$), with 3PL buffer stock (H2C) having a marginally significant effect ($p < 0.1$).

Surprisingly, the call-off risk and on-hand safety stock do not have a significant direct impact on order lead-time as they do on service level, especially in the focal environment where there is a border separating the 3PL warehouse and the manufacturing plant. After a careful review, we conclude that delays due to border crossing or local traffic conditions typically take several hours while delays due to replenishment delivery uncertainty or capacity issues can take days to even weeks. Therefore, call-of delays are relatively smaller than replenishment

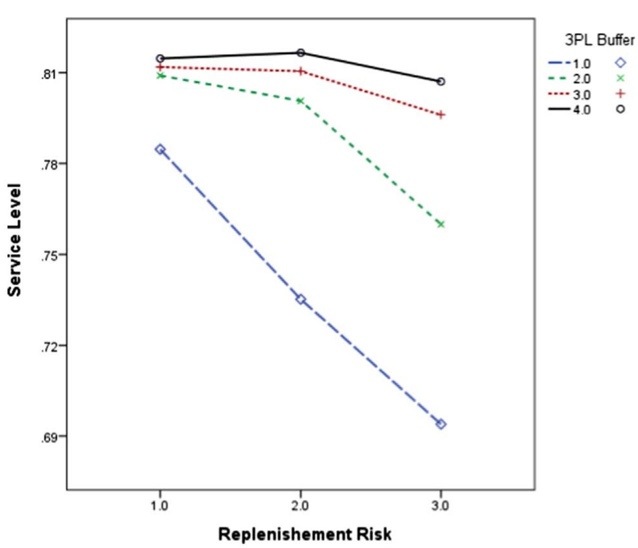

Fig. 4. Moderating effects.

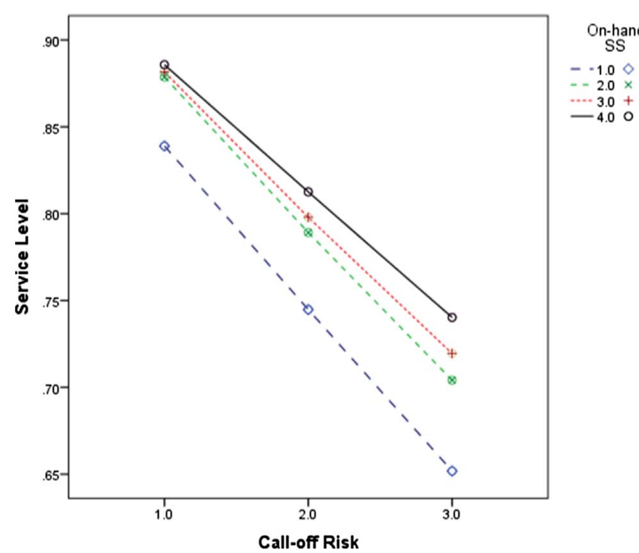

Fig. 4. (*continued*)

delays and are less significant from a statistical standpoint when the performance is measured by order lead-time. Similarly, on-hand safety stock levels are much lower than the 3PL buffer stock levels and are, generally, not enough to fulfill daily orders completely. So call-off deliveries are required on the daily basis even when there is some inventory on hand. Therefore, the on-hand safety stock does not significantly affect the firm's order lead-time performance. Consequently, hypotheses H1D and H2D are not supported.

The moderating effect of 3PL buffer stock on the relationship between replenishment risk and order lead-time performance (i.e., H3C) is significant as expected. Fig. 4(c) depicts such a "positive" moderating effect: when 3PL buffer inventory level increases, the order lead-time decreases, indicating better performance. One can also observe that when 3PL buffer stock is set at a very high level, the effect of replenishment risk on order lead-time will be fully mitigated. When buffer

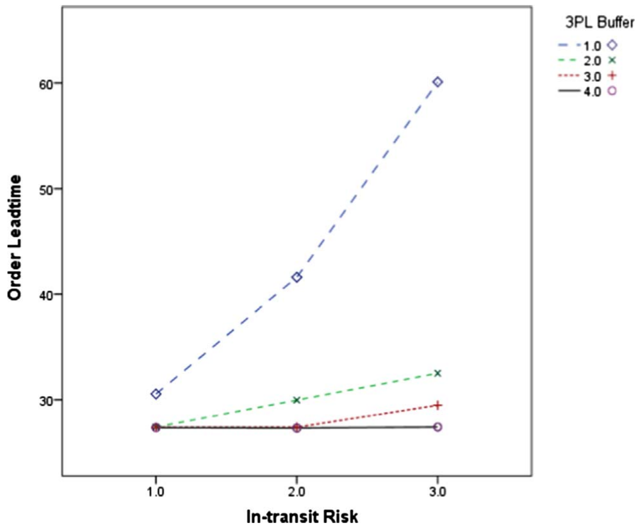

Fig. 4. (*continued*)

stock level decreases, the impact of replenishment risk on order lead-time becomes more significant and critical. In contrast, the moderating effect of on-hand safety stock on the relationship between call-off risk and order lead-time performance is not significant, i.e., H3D is not supported. This is not surprising after observing the insignificant direct effects of both factors on order lead-time.

5.2.3. Stronger effects on service level and order lead-time

To test whether the difference between the coefficients of replenishment risk and call-off risk is statistically significant in both models, we computed the appropriate *t*-statistic for each model follows:

Model 1 (DV = service level): $$t_1 = \frac{B_{call-off\ risk} - B_{replenish\ risk}}{\sqrt{\frac{s^2_{call-off\ risk} + s^2_{replenish\ risk}}{N}}}$$

Model 2 (DV = order leadtime): $$t_2 = \frac{B_{replenish\ risk} - B_{call-off\ risk}}{\sqrt{\frac{s^2_{replenish\ risk} + s^2_{call-off\ risk}}{N}}}$$

where B is the unstandardized coefficient of a variable in the regression models, s is the standard error of B, and N is the sample size. For the first model in which service level is the performance measure, the resultant *t*-value is 3209.65, an extremely significant value. This suggests that the effect of call-off risk on service level is much greater than that of replenishment risk. Thus, H4A is strongly supported. As for the second model in which order lead-time is the performance measure, the *t*-value is 80.83, indicating that the effect of replenishment risk on order lead-time is much greater than that of call-off risk. Specifically, we found no significant direct effect of call-off risk on firm's order lead-time performance while the direct effect of replenishment risk is significant. Therefore, the significant difference between these two factors on order lead-time is evidenced and thus, H4B is strongly supported.

5.3. Managerial implications

In a JIT system, "time" is always a critical element in assessing a manufacturing firm's performances. In this research, we adopt two time-related performance measures that are commonly used by JIT firms: service level and order lead-time. We found that these two time-related performance metrics are affected differently by transportation risks in different segments of a supply chain. This sheds light on our focal company, Wistron Corp., in how to better manage its supply chain in order to enhance its performance. Our findings suggest that Wistron's performance in service level is predominantly attributed to delays due to border crossing and custom inspections. Wistron should work closely with its 3PL service providers, aiming to cut down the call-off delivery uncertainties. For instance, 3PL service providers need to ensure that there are always trucks available for deliveries. Additionally, 3PL service providers should strive to obtain several certifications such as Customs-Trade Partnership Against Terrorism (C-TPAT), and Free and Secure Trade (FAST). Specifically, the C-TPAT importers are four to six times less likely to incur a security or compliance examination, according to U.S. Customs and Border Protection's (CBP) Web site. With

Table 4
Regression results: DV = Order Leadtime.

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	R Square
		B	Std. Error	Beta			
1	(Constant)	27.327	10.314		2.650	0.008	
	Capacity Risk	1.175	6.389	0.003	0.184	0.854	
	Forecast Error %	19.636	41.503	0.009	0.473	0.636	0.000
2	(Constant)	16.910	11.696		1.446	0.148	
	Capacity Risk	1.171	6.367	0.003	0.184	0.854	
	Forecast Error %	21.782	41.359	0.010	0.527	0.598	
	Replenishment Risk	6.914	1.462	0.088	4.729	0.000	
	Call-off risk	2.509	19.492	0.002	0.129	0.898	0.008
3	(Constant)	54.333	11.669		4.656	0.000	
	Capacity Risk	12.850	6.171	0.037	2.082	0.037	
	Forecast Error %	−6.428	39.900	−0.003	−0.161	0.872	
	Replenishment Risk	19.284	1.622	0.245	11.892	0.000	
	Call-off risk	5.989	18.750	0.006	0.319	0.749	
	3PL Buffer	−49.040	3.201	−0.318	−15.318	0.000	
	On-hand SS	−0.890	1.256	−0.013	−0.709	0.479	0.083
4	(Constant)	−5.828	15.749		−0.370	0.711	
	Capacity Risk	13.930	6.103	0.041	2.282	0.023	
	Forecast Error %	−6.582	39.458	−0.003	−0.167	0.868	
	Replenishment Risk (1C)	63.005	5.555	0.801	11.342	0.000	
	Call-off risk (1D)	8.745	35.596	0.008	0.246	0.806	
	3PL Buffer (2C)	14.118	8.309	0.092	1.699	0.089	
	On-hand SS (2D)	−0.642	3.281	−0.009	−0.196	0.845	
	Replenishment Risk × 3PL Buffer (3C)	−44.219	5.379	−0.850	−8.221	0.000	
	Call-off Risk × Oh-SS (3D)	−0.082	1.522	−0.003	−0.054	0.957	0.104

C-TPAT certification, goods are also more secured and less likely to be delayed or damaged as a result of customs inspections. The FAST certification provides 3PL carrier access to dedicated lanes at border crossings and the number of inspections is also reduced. When inspected, it allows front-of-the-line processing for customs inspections. With C-TPAT and FAST certifications, the time spent at customs on the border will be significantly reduced, resulting in more consistent delivery time between the 3PL warehouse and the manufacturing plant. Winstron and its suppliers should urge their current 3PL service providers that do not have these certifications to strive to obtain these useful certifications.

While call-off risk significantly affects a firm's performance in service level, it is, in contrast, not as critical to a firm's performance in order lead-time as we originally thought. Our findings suggests that Wistron's order lead-time performance is predominantly affected by the replenishment activities; call-off delays due to border crossing plays very little role. Specifically, we found that both supplier capacity risk and replenishment lead-time uncertainty are critical to order lead-time. Therefore, to enhance its order lead-time performance, Wistron should continue to share forecast information with its suppliers, so that suppliers can better plan for their availability of capacity and replenish their component inventory levels in the 3PL warehouse on time. Replenishment risk can be related to transportation itself or to delays caused by customs clearance. To reduce the replenishment risk, Wistron can urge its suppliers to use freight forwarders that have obtained the Cargo Network Service (CNS) and Cargo 2000 membership, which allows 3PL service providers to decrease time required for manual track-and-trace and to adopt standardized processes and paperless shipping management. As a result, air cargo shipments can move more expediently and can cut down the transportation lead-time and the level of variation at the same time.

Surprisingly, the R^2 value of the second model is only around 10%. This indicates that the key factors we considered, altogether, explain very little about the variance of firm's order lead-time performance. In our simulation model, each order takes, on average, around 12–18 h to complete. The occasional call-off delays for 4–6 h do not seem to present a significant threat to order lead-time performance over the long run. Although delays due to a combination of supplier capacity issues and in-transit delays may significantly increase the total order lead-time, the probability of such serious delays is relatively small and thus has limited impact on delivery performance. Perhaps R^2 value may increase and key variables will be more likely to be significant if the production lead-time is shortened. In other words, if the portion of order lead-time accounted for by the required production time is shorter, a delay of 4–6 h may significantly increase its impact on order lead-time performance. In this study, however, we intend to set-up all parameter values that truly reflect the actual operational activities that are observed at Wistron. That way, the results of this study can provide Wistron's managers with most useful insights that can help improve their performance most effectively.

6. Conclusions

Motivated by the daily dilemma encountered by Wistron and many other maquiladoras inside the FTZs, this study investigates the effects of multiple transportation risks and multi-locational safety stock levels on firms' delivery performance in a JIT environment. Forecast of predetermined planning horizon is provided to the supplier on a regular basis and the supplier is responsible for replenishing the buffer stock levels in the 3PL warehouse. The replenishments are subject to delays due to capacity or transportation issues. Meanwhile, the call-off deliveries are also experiencing high risk of delays due to border crossing and customs inspection, which requires the JIT manufacturers to carry certain level of safety stocks on site. This research controls the capacity and forecasting risks, and analyzes and compares the impact of multiple transportation uncertainties on a firm's service level and order lead-time performance.

We found that both transportation lead-time risks and multi-locational safety stocks significantly affect a firm's service level. Specifically, we found that call-off risk has a greater impact on service level than replenishment lead-time risk. However, the effects of call-off uncertainty and on-hand safety stock on order lead-time performance are not as significant as we previously thought; only replenishment lead-time risk and 3PL safety stock play a significant role in firm's order lead-time performance. Understanding these dynamics allows firms to reduce their exposure to different types of delivery risks and to better manage their JIT supply chains.

There are several potential extensions for future research. First, this research considers only one product, one raw material, and one supplier in the focal supply chain. Analyses of multi-locational safety stocks and multiple lead-time risks involved with products of multiple-echelon bill-of-material (BOM), multiple raw materials, and multiple suppliers in JIT environments need to be further explored. Second, restrictions in production hours, delivery quantity, delivery time, order release time, and production capacity can be also included in the simulation model in order to reflect more complex real world situations. Third, cost elements can be incorporated into the simulation models. By taking the costs into account, financial impacts of key risk factors and safety stock levels on performance can be examined. As a result, advantages and disadvantages between using 3PL party warehouses on both sides of the border can also be investigated and compared.

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