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A multi-objective approach to supply chain visibility and risk

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ABSTRACT

This paper investigates the twin effects of supply chain visibility (SCV) and supply chain risk (SCR) on supply chain performance. Operationally, SCV has been linked to the capability of sharing timely and accurate information on exogenous demand, quantity and location of inventory, transport related cost, and other logistics activities throughout an entire supply chain. Similarly, SCR can be viewed as the likelihood that an adverse event has occurred during a certain epoch within a supply chain and the associated consequences of that event which affects supply chain performance. Given the multi-faceted attributes of the decision making process which involves many stages, objectives, and stakeholders, it beckons research into this aspect of the supply chain to utilize a fuzzy multi-objective decision making approach to model SCV and SCR from an operational perspective. Hence, our model incorporates the objectives of SCV maximization, SCR minimization, and cost minimization under the constraints of budget, customer demand, production capacity, and supply availability. A numerical example is used to demonstrate the applicability of the model. Our results suggest that decision makers tend to mitigate SCR first then enhance SCV.

1. Introduction

Asia is a major contributor to many a global supply chain with many manufacturers, contractors and supply bases located throughout Asia, where more than 7000 parts suppliers service the automotive industry of the top ten vehicle manufacturers alone. According to Rajasekera (2011), Japan is a source of key electronic and automotive components and feeds the global supply chain to destinations such as the US, Mexico, and Canada. Nearly every firm making any of the most demanding consumer products needs Japanese components or raw materials because of its intrinsic product quality and technological edge. The disruption caused by the March 11 earthquake, tsunami and nuclear reactor crises in Japan has been felt in these industries, especially when the impact on the supply chain of these two industries is exacerbated by the subsequent major flooding in Thailand. The role of the parts supplies and the raw materials suppliers in Japan and Thailand is critical for the global supply chain of large vehicle manufacturers such as Toyota who for instance is served by a significant tier one supplier Denso (which supplies 50% of its production to Toyota), who in turn is served by Marcon Denso, a tier two single source supplier who for cost reasons draws its labor force from the cheaper rural areas in Japan near where the tsunami struck. Krebs (2011) has reported on the commercial impact of the risk of a delay of a Marcon Denso part to Toyota, who incidentally reported a decline of 77% in earnings in 2011. Indeed, most of the smaller suppliers to Japanese automotive and electronic suppliers are single source. The risk of their production being affected by natural disasters will lead to undesired shipment delays, and disrupting the production schedules of downstream companies in the chain (Jüttner, 2005).

Zsidisin (2002) defines this form of supply risk as the potential occurrence of an incident associated with inbound supply from individual supplier failures or the supply market in which its outcomes result in the inability of the buying firm to meet demand. As mentioned, events affecting one supply chain entity or process will interrupt the operations of other supply chain members either directly or indirectly and in more ways than one. Supply chain disruptions have become a critical issue for many companies. In the literature, Zsidisin (2002) has studied the assessment of supply risk while Smeltzer and Siferd (1998) illustrated proactive supply management practices involving risk management. Sanders and Manfredo (2002) have proposed estimates of the downside risk on commodities by using a Value-at-Risk approach. Further, Zsidisin (2003) studied the supply characteristics that affect managerial perceptions of supply risk and created a classification of supply risk sources. A review of the research on the sources of potential supply

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risk is also provided by Zsidisin (2003), Goh, Lim and Meng (2007), and Zhang, Coronado Mondragon, and Lalwani (2010). From the literature, it becomes apparent that a main consideration in supply chain risk (SCR) management is the visibility of the risk. For instance, good visibility in the supply chain can yield benefits in operations efficiency (e.g. Smaros, Lehtonen, Appelqvist, & Holmstrom, 2003) and more effective supply chain planning (Petersen, Ragatz, & Monczka, 2005). While we acknowledge that SCR is wide ranging, we limit our scope of SCR in this paper to supply risk given the recent development of events in this area.

Separately, Harland, Brenchley, and Walker (2003) report that in the supply chains examined, less than half of the risk was visible to the focal company. Thus, one key question arising from the two Asian disasters and the extant literature that begs an answer is: how to choose the parts supplier in order to minimize the supply risk / disruptions due to the supply chain and how to invoke as high a visibility as possible without exceeding the production or total budget.

Indeed, the study of supply chain visibility (SCV) has drawn much recent interest from both researchers and practitioners in supply chain management (Barlett, Julien, & Baines, 2007). According to Enslow (2006), about 79% of the large companies surveyed globally cited the lack of SCV as their top concern. Further, an alarming 90% of the responding supply chains asserted that their existing supply chain technology is incapable of providing timely information to prepare budget and cash flow plans for the finance department. Delen, Hardgrave, and Sharda (2007) and Zhou (2009) claim that through the implementation of RFID, SCV can be enhanced to eliminate supply chain barriers by enabling and sharing information and eventually improve the performance of a supply chain. Ouyang (2007) further shows that SCV implementation can enhance supply chain stability and mitigate the bullwhip effect. Implementation is currently undertaken by sharing point-of-sales (POS) information across a supply chain. This concurs with Goh, De Souza, Zhang, Wei, and Tan (2009) who define SCV as the capability of a supply chain actor to have access to or to provide the required timely information/knowledge involved in the supply chain from/to relevant supply chain partners for better decision support. While some work on visibility has been undertaken, this area is still nascent (see e.g. Smaros et al., 2003). Zhang, Goh, and Meng (2010) have also reported that global logistics operators clearly seemed to benefit from the visibility of the end-to-end supply chain. Thus, there is a need to better understand the joint issues of risk and visibility particularly in the context of multiple objectives. As such, it warrants further in-depth study, especially when combined with other aspects of supply chain management such as risk, complexity, or disruptions.

This paper makes the following contribution to the literature. We consider specifically the context of a selection of a parts supplier who has to strategically meet a triple objective of cost, risk and visibility for the downstream supply chain. This problem is new and novel to the field and is highly practical and timely in the light of the recent spate of events affecting the automotive and electronics supply chains globally.

2. Model development for SCV and SCR

A mathematical model is developed incorporating SCV and SCR so that the appropriate suppliers can be identified. The proposed multiple objective integer programming model includes three objectives namely visibility maximization, risk minimization, and cost minimization. The formulation of the model is as follows.

Notations
i index of suppliers
j index of parts
Decision variables
Q_{ij} quantity of part i provided by supplier j
Y_{ij} a binary variable determined by whether part j is supplied by supplier i

$$Y_{ij} = \begin{cases} 1 & \text{if part i is supplied by supplier } j \\ 0 & \text{otherwise} \end{cases}$$

Parameters
B_i budget available to enhance SCV for part i
C_j production capacity of supplier j
CR_{ij} cost of reducing supply risk for part i from supplier j
CV_{ij} cost of enhancing SCV to current level for part i from supplier j
D_i demand for part i
m_{ij} minimum order quantity for part i required by supplier j
P_{ij} purchase price for part i supplied by supplier j
IR_{ij} impact (financial loss) caused by supply risk for part i from supplier j
R_{ij} supply risk for part i from supplier j
R_i maximum allowable supply risk for part i
V_{ij} supply chain visibility incurred if part i is supplied by supplier j
V_i minimum amount of visibility needed for part i

Model:

$$Max\ visibility = \sum_i \sum_j V_{ij} Y_{ij} \tag{1}$$

$$Min\ risk = \sum_i \sum_j R_{ij} Y_{ij} \tag{2}$$

$$Min\ cost = \sum_i \sum_j V_{ij} CV_{ij} Y_{ij} + \sum_i \sum_j R_{ij} CR_{ij} Y_{ij} + \sum_i \sum_j IR_{ij} Y_{ij} + \sum_i \sum_j P_{ij} Q_{ij} \tag{3}$$

Subject to :

$$\sum_j V_{ij} CV_{ij} Y_{ij} \leqslant B_i \quad \text{for each } i \tag{4}$$

$$\sum_j V_{ij} Y_{ij} \geqslant V_i \quad \text{for each } i \tag{5}$$

$$\sum_j Q_{ij} = D_i \quad \text{for each } i \tag{6}$$

$$\sum_i Q_{ij} \leqslant C_j Y_{ij} \quad \text{for each } j \tag{7}$$

$$\sum_j R_{ij} Y_{ij} \leqslant R_i \quad \text{for each } i \tag{8}$$

$$Q_{ij} \geqslant m_{ij} Y_{ij} \quad \text{for each } i,j \tag{9}$$

$$Q_{ij} \leqslant N Y_{ij} \quad \text{for each } i, \tag{10}$$

$$Q_{ij} \geqslant 0 \quad \text{for each } i,j \tag{11}$$

$$Y_{ij} \in \{1,0\} \quad \text{for each } i,j \tag{12}$$

Constraint (4) restricts the spending of SCV under a planned budget for all suppliers. Constraint (5) implements the minimum amount of visibility for each part. Constraint set (6) enforces the fulfillment of the demand quantity for each part. Constraint set (7) serves as the capacity constraint for each supplier. Constraints in set (8) limit the maximum allowable supply risk for each part supplied by all suppliers. Constraint (9) specifies the minimum order quantity of each part for all suppliers. Set (10)