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Risk Management in Supply Chain using Consistent Fuzzy Preference Relations

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Abstract
Nowadays, supply chains are exposed to numerous risks. Thus, to success in risky business environment, it is imperative for firms to systematically manage supply chain risks. Risk management is the identification, assessment, and prioritization of supply chain risks. The purpose of this paper is to propose a comprehensive approach to risk management in supply chains. Thus, by an appropriate review of the literature, supply chain risk sources are identified in six areas. Then, a CFPR method is used to determine the relative importance of each identified risk. The results indicate that financial risks demand risks and supply risks are the most important risks in the SMEs context.

1. Introduction

A supply chain is a network of organizations that are involved, through upstream and downstream linkages, in different processes and activities that produce value to consumers (Christopher, 1992). Supply chain management (SCM) is defined as the integration of the processes of plan, source, make, deliver and return along the supply chain (Supply-Chain Council 2008). SCM involves the management of complex financial, information and materials flows across multiple functional areas both within and among firms (Helo and Szekely, 2005). The goals are to add value to the processes that deliver innovative, high-quality, low-cost products on time with shorter development cycles and greater responsiveness (Fawcett and Magnan, 2004; Darwish, 2015). To success in today's competitive business environment, SCM is of critical importance. However, modern supply chains are very complex. Maintaining uninterrupted supply chain flows are difficult, as there are always associated risks in each of these flows (Faisal 2009). This necessitates firms to identify and manage supply chain risks.

The notion of risk within supply chains is a recent topic of interest (Khan and Burnes, 2007, Jüttner, 2005). Various trends such as globalization, dynamic business environment, increased competitive pressure, increased demand for on-time delivery, outsourcing, rapid technological change, higher dependency on external vendors, and short product lifecycles highlight the importance of supply chain risk management (SCRM) (Christopher and Peck, 2004, Norrman

and Jansson, 2004, Faisal, 2009; Zsidisin et al., 2000; Trkman and McCormack, 2009; Olson and Wu, 2011; Christopher and Lee, 2004; Punniyamoorthy et al. 2013). SCRM is an area that has grown significantly since 2000 and has gained widespread attention from both academics and industry (Zsidisin, 2003; Peck, 2005; Ellis et al., 2010; Tummala and Schoenherr, 2011, Manuj and Mentzer, 2008, Trkman and McCormack, 2009). In the supply chain context, different definitions of risk are presented in the literature. Supply chain risk is defined as "the variation in the distribution of possible supply chain outcomes, their likelihoods, and their subjective values" (Jüttner et al., 2003). Christopher (2003) defined supply chain risk as "any risk to the information, material and product flow from original suppliers to the delivery of the final product". SCRM is also defined as "the management of supply chain risks through coordination or collaboration among the supply chain partners so as to ensure profitability and continuity (Tang, 2006).

Risk could create problems in a supply chain (Tang and Musa, 2010).Supply chain risks can have serious negative impacts on the firms' operations (Hendricks and Singhal 2005, Craighead et al. 2007). Thus, to survive, it is imperative for firms to have a proper SC risk management. The failure to effectively manage supply chain risk may result in economic and financial losses, reductions in product quality, delivery delays and loss of reputation (Cousins et al. 2004). Thus, the goal of SCRM is "the ability to react quickly to ensure continuity" (Van Hoek, 2003; Rowbottom, 2004). SCRM is a difficult task as individual risks are often interconnected (Chopra and Sodhi, 2004). However, firms that understand the importance of supply chain risk often do not know where to start (Kiser and Cantrell 2006). According to Punniyamoorthy et al. (2013) the effective way to manage the supply chain risk begins with identification of various risks followed by prioritization of these risks. Prioritization of risks is one the important constituent of risk management process (Faisal, 2009; Darwish, 2015). Prioritization helps firms to focus attention on the most important risks (Hallikas et al., 2002). Small and medium enterprises (SMEs) are of critical importance to many economics. SMEs form the majority at tier II and tier III levels of a supply chain. The severity of supply chain failures are more felt by SMEs. This is because of the limited resources and lack of adequate planning to counter supply chain risks (Faisal, 2009). This paper attempts to enhance the understanding of supply chain risks. Thus, the main objective of the paper is to identify and prioritize supply chain risks. Identification of potential risk sources which disrupt the performance of the supply chain and the relative importance of them can help firms to manage supply chain risks and develop strategies to mitigate the adverse effects of them. The remainder of the paper is organized as follows. Section 2 briefly reviews supply chain risk literature. Research methodology is presented in section 3. Conclusion and final remark is presented in section 4.

2. Supply Chain Risks

The first step in the supply chain risk management process is risk identification and classification Risk identification involves a comprehensive and structured determination of potential SC risks (Manuj and Mentzer 2008, Tummala and Schoenherr, 2011, Punniyamoorthy et al. 2013). Risk, in the context of SCM, is a multi-dimensional construct (Zsidisin, 2003; Zsidisin et al., 2004). Christopher and Peck (2004) classified SCRs into two dimensions: internal to the firm, external to the firm but internal to the supply chain and external to the supply chain

network. Tang (2006) classified SCRs risks two categories: operational risk and disruption risk. Operational risks are due to the interactions between firms across the supply chain (supply risk, demand risk, and etc.). Disruption risks are due to the interactions between the supply chain and its environment (such as terrorism, or natural disasters and etc.). Manuj and Mentzer (2008) classified supply chain risks in four categories: supply, demand, operational, and security risks. Faisal (2009) categorized supply chain risk under four dimensions: physical, financial, relational and informational. Rao and Goldsby (2009) classified SCRs risks five categories: Environmental factors, Industry factors, Organizational factors, Problem-specific factors and Decision-maker factors. Zhao et al (2013) considered two types SCRs: supply risk and demand risk. Jüttner (2005) delineated three categories (supply, demand, and environmental), and Chopra and Sodhi (2004) proposed nine categories (disruptions, delays, systems, forecast, intellectual property, procurement, receivables, inventory, and capacity).

Table 1

Risk source	Risk variable	Reference
Demand Risk (DR)	D1. Competitor moves	Cucchiella and Gastaldi (2006), Manuj and Mentzer (2008)
	D2. Delays in delivery to customers	Chopra and Sodhi (2004), Blackhurst et al. (2008), Punniyamoorthy et al. (2013)
	D3. Forecast errors	Zhao et al (2013), Chopra and Sodhi (2004), Blackhurst et al. (2008), Manuj and Mentzer (2008), Oke and Gopalakrishnan (2009), Faisal (2009)
	D4. Market saturation	Soni and Kodali (2013),
	D5. Volatile customer demand	Soni and Kodali (2013), Manuj and Mentzer (2008), Sodhi and Lee, (2007) 16, Cucchiella and Gastaldi (2006), Punniyamoorthy et al. (2013)
Environment Risk (ER)	E1. Macroeconomic uncertainty	Soni and Kodali (2013), Shashank and Goldsby, 2009, Punniyamoorthy et al. (2013)
	E2. Natural disasters	Chopra and Sodhi (2004), Sheffi and Rice 2005, Blackhurst et al. (2008), Oke and Gopalakrishnan, 2009, Punniyamoorthy et al. (2013)
	E3. Policy Uncertainty	Manuj and Mentzer, 2008; Shashank and Goldsby, 2009), Punniyamoorthy et al. (2013)

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	E4. Social uncertainty	Tang and Tomlin, 2008; Shashank and Goldsby, 2009, Punniyamoorthy et al. (2013)
Financial Risk (FR)	F1. Business risks	Zsidisin et al. (2000), Faisal (2009)
	F2. Cost/price risk	Zsidisin et al. (2000), Faisal (2009)
	F3. Exchange rate risks	Tummala and Schoenherr, 2011, Chopra and Sodhi (2004), Blackhurst et al. (2008), Faisal (2009)
	F4. Investment risks	Faisal (2009)
Information Risk (IR)	I1. Breakdown of IT infrastructure	Chopra and Sodhi, 2004; Blackhurst et al. 2008), Punniyamoorthy et al. (2013)
	I2. Distorted information	Blackhurst et al. (2008),
	I3. Inadequate Information Security	Blackhurst et al. (2008), Faisal (2009)
	I4. Information delay	Cucchiella and Gastaldi (2006), Punniyamoorthy et al. (2013)
	I5. Wrong choice of communication	Punniyamoorthy et al. (2013)
Operational Risk (OR)	O1. Capacity Inflexibility	Chopra and Sodhi (2004), Giunipero and Eltantawy (2004); Blackhurst et al. (2008), Faisal (2009), Punniyamoorthy et al. (2013)
	O2. Design changes	Faisal (2009)
	O3. Disruption in production	Punniyamoorthy et al. (2013)
	O4. Inventory risk	Chopra and Sodhi (2004), Faisal (2009)
	O5. Production technological Changes	Zsidisin et al. (2000), Giunipero and Eltantawy (2004); Cucchiella and Gastaldi (2006), Faisal (2009)
	O6. Variability in production process	Van der Vorst and Beulens (2002), Punniyamoorthy et al. (2013)
Supply Risk	S1. Dependency on single	Tummala and Schoenherr, 2011, Hauser (2003), Sodhi and Lee (2007), Tang and Tomlin

(SR)	supplier	(2008), Punniyamoorthy et al. (2013)
	S2. Inflexibility of supplier	Chopra and Sodhi (2004)
	S3. Poor delivery performance	Faisal (2009)
	S4. Supplier poor quality	Zhao et al (2013), Cucchiella and Gastaldi (2006), Manuj and Mentzer (2008), Faisal (2009), Tuncel and Alpan (2010), Punniyamoorthy et al. (2013)
	S5. Supplier bankruptcy	Kleindorfer and Saad, (2005), Blackhurst et al. (2008), Manuj and Mentzer (2008), Punniyamoorthy et al. (2013)

As it is obvious, there are no consistently accepted dimensions of SCRs and several different classifications are reported in the literature. In this section, supply chain risks are categorized under six major risk constructs. The review of categories of risk in supply chain management (SCM) is given in Table 1. Supply risk is the "probability 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 purchasing firm to meet customer demand or cause threats to customer life and safety" (Zsidisin, 2003). Supply side risks reside in supplier activities, relationships and purchasing (Wagner and Bode, 2009). Demand side risks result from disruptions emerging from downstream supply chain operations (Jüttner 2005).Risks in supply chains due to the flows of cash between firms can be classified under financial risks. Risks in supply chains due to the flows of information between firms can be classified under information risks. Operational risk can be defined as risks initiated with operational events. Operational risks are associated with planning and production capabilities. Environment risks are due to the interactions between the supply chain network and its environment (Juttner et al. 2003). Environmental risk can arise due to physical, social, political, legal or economic environment (Ghadge et al., 2012).

3. Consistent fuzzy preference relations

In traditional pairwise comparison methodologies (AHP or ANP) a decision-maker has to provide$n\ (n-1)/2$ judgments fora preference matrix which has *n* components. To simplify the pairwise comparison, consistent fuzzy preference relations (CFPR) proposed by Herrera-Viedma et al.(2004)is used in this paper, as it only requires *n - 1*judgments for a preference matrix with *n* elements. Since CFPR reduce judgment times, it is possible to assure better consistency. The computational procedure to determine the relative importance of risk sources and variables base on CFPR is discussed in the following (Chang et al. 2013, Wang and Lin, 2009).

Step 1: Risk identification. By an appropriate review of literature, 29 risk variables identified that are categorized under 6 main risk sources (table 1).

Step 2: Degree of preference. Linguistic terms and the corresponding number that are used to provide pairwise comparisons are presented in table 2.

Table 2: Linguistic scale

Definition	Relative importance
Equally important	1
Moderately more important	3
Strongly more important	5
Very strongly more important	7
Absolutely more important	9
Intermediate values	2, 4, 6, 8

Step 3: Construct pairwise comparison matrices amongst the risk factors (C_i, $i = 1, \ldots, n$). The decision makers are asked to provide pair-wise comparisons for a set of $n - 1$ preference values. In this research, 14 experts, both from academic and industry (8 SME manager), are asked to determine the importance of different risk sources (criteria level) and variables (sub-criteria level) based on table 2. The pair-wise comparison matrix provided by decision maker 1 for the criteria level is shown in Table 3.

Table 3: Fuzzy preference pairwise comparison matrix of decision maker 1

	FR	DR	SR	IR	OR	ER
FR	1	3				
DR		1	2			
SR			1	3		
IR				1	1	
OR					1	3
ER						1

Step 4: Transform the preference value $a_{ij} \in \left[\frac{1}{9}, 9\right]$ into $p_{ij} \in [0,1]$ through Eqs. 1.

$$p_{ij} = \frac{1}{2} \times \left(1 + log_9 a_{ij}\right) \quad (1)$$

Then, calculate the remaining p_{ij}^k by using Eqs.2, 3 and4 (table 4).

$$p_{ij} + p_{ji} = 1 \quad (2)$$

$$p_{ji} = \frac{j - i + 1}{2} - p_{i(i+1)} - p_{i+1(i+2)} - \cdots - p_{j-1(j)} \quad (3)$$

$$p_{ij} + p_{jk} + p_{ki} = 3/2 \quad (4)$$

Table 4: Transformed fuzzy preference values of decision maker 1

	FR	DR	SR	IR	OR	ER
FR	0.5	0.75	0.9077	1.1577	1.1577	1.4077
DR	0.2	0.5	0.6577	0.9077	0.5	0.5
SR	0.0923	0.3423	0.5	0.75	0.75	1
IR	0.1577	0.0923	0.25	0.5	0.5	0.7
OR	0.1577	0.5	0.25	0.5	0.5	0.75
ER	0.4077	0.5	0	0.25	0.25	0.5

Since this preference matrix contains values included in the interval [-*a*, 1+*a*] rather than in the interval [0, 1], then a transformation function is used to preserve reciprocity and additive transitivity.The transformation is calculated by Eq.5.

$$f(p_{ij}) = \frac{p_{ij} + a}{1 + 2a} \quad (5)$$

Where *a* indicate the absolute value of the minimum in this preference matrix (table 5).

Table 5: Preference values transformed by linear solution

	FR	DR	SR	IR	OR	ER
FR	0.5	0.6377	0.7246	0.8623	0.8623	1
DR	0.3623	0.5	0.5869	0.7246	0.5	0.5
SR	0.2754	0.4131	0.5	0.6377	0.6377	0.7754
IR	0.1377	0.2754	0.3623	0.5	0.5	0.6377
OR	0.1377	0.5	0.3623	0.5	0.5	0.6377
ER	0	0.5	0.2246	0.3623	0.3623	0.5

Likewise, use the above computational procedures to calculate the fuzzy preference relation matrices of the other13decision makers. Step 6: aggregation. Aggregate the fuzzy preference relations matrices to obtain the synthetic importance weights of risk sources. Let p_{ij}^{k} denote the transformed fuzzypreference value of the k^{th} decision maker for assessing risk factor *i* and risk factor *j*. The average value method (Eq. 6) is used to integrate the judgments of 14decision makers. Table 6 shows the aggregated pairwise comparison matrix obtained by Eq. (6).

$$p_{ij} = \frac{1}{m}\left(p_{ij}^{1} + p_{ij}^{2} + \cdots + p_{ij}^{m}\right) \quad (6)$$

Table 6: Aggregated pairwise comparison matrices of 14 evaluators

	FR	DR	SR	IR	OR	ER
FR	0.5	0.6158	0.7111	0.8178	0.8896	1
DR	0.3842	0.5	0.5953	0.7020	0.5	0.5
SR	0.2889	0.4047	0.5	0.6067	0.6784	0.7889
IR	0.1822	0.2980	0.3933	0.5	0.5718	0.6822
OR	0.1104	0.5	0.3216	0.4282	0.5	0.6104
ER	0	0.5	0.2111	0.3178	0.3896	0.5

Step 7: Normalize the aggregated fuzzy preference relation matrices. Use h_{ij} to indicate the normalized fuzzy preference value of each risk criteria (Eq. 7) (table 7).

$$h_{ij} = \frac{p_{ij}}{\sum_{i=1}^{n} p_{ij}} \quad , i, j = 1,2, \dots, n \qquad (7)$$

Table 7: Normalized matrix of priority weight and rank of influential factors

	FR	DR	SR	IR	OR	ER
FR	0.3411	0.2185	0.2602	0.2425	0.2520	0.2450
DR	0.2621	0.1774	0.2179	0.2082	0.1417	0.1225
SR	0.1971	0.1436	0.1830	0.1799	0.1922	0.1933
IR	0.1243	0.1057	0.1439	0.1483	0.1620	0.1671
OR	0.0754	0.1774	0.1177	0.1270	0.1417	0.1496
ER	0.0000	0.1774	0.0773	0.0942	0.1104	0.1225

Step 8: calculate the importance weight of each risk criteria (Eq. 8).

$$w = \frac{1}{n}\sum_{i=1}^{n} h_{ij} \qquad (8)$$

Table 9 gives the importance weight and rank of each risk factor assessed by ten evaluators. Therefore, the rank of the risk factor weight is substituted as

Table 9: gives the importance weight and rank of each risk factor

FR	0.2599
DR	0.1883
SR	0.1815

IR	0.1419
OR	0.1314
ER	0.0970

To calculate the importance weight for each set of sub-criteria, above computational procedures is repeated. Table 10 shows the importance weight for each set of sub-criteria.

Table 10: Importance weight of risk variables (sub-criteria)

Risk sources (criteria level)	weight	Risk variable (sub-criteria level)	Local Wight	Global weight	Rank
Demand risk	0.1883	D1. Competitor moves	0.1395	0.0263	17
		D2. Delays in delivery to customers	0.2321	0.0437	6
		D3. Forecast errors	0.3164	0.0596	3
		D4. Market saturation	0.1203	0.0227	23
		D5. Volatile customer demand	0.1917	0.0361	8
Environment risk	0.0970	E1. Macroeconomic uncertainty	0.3550	0.0344	12
		E2. Natural disasters	0.1492	0.0145	29
		E3. Policy Uncertainty	0.2808	0.0272	16
		E4. Social uncertainty	0.2150	0.0208	25
Financial Risk	0.2599	F1. Business risks	0.1385	0.0360	9
		F2. Cost/price risk	0.2128	0.0553	5
		F3. Exchange rate risk	0.3615	0.0940	1
		F4. Investment risk	0.2872	0.0746	2
Information risk	0.1419	I1. Breakdown of IT infrastructure	0.2061	0.0292	13
		I2. Distorted information	0.2458	0.0349	11
		I3. Inadequate Information Security	0.1973	0.0280	14

		I4. Information delay	0.1823	0.0259	18
		I5. Wrong choice of communication	0.1685	0.0239	20
Operational risk	0.1314	O1. Capacity Inflexibility	0.1351	0.0178	28
		O2. Design changes	0.1576	0.0207	26
		O3. Disruption in production	0.1747	0.0230	21
		O4. Inventory risk	0.1747	0.0230	22
		O5. Production technological Changes	0.2087	0.0274	15
		O6. Variability in production process	0.1492	0.0196	27
Supply risk	0.1815	S1. Dependency on single supplier	0.1413	0.0256	19
		S2. Inflexibility of supplier	0.1978	0.0359	10
		S3. Poor delivery performance	0.2321	0.0421	7
		S4. Supplier poor quality	0.3108	0.0564	4
		S5. Supplier bankruptcy	0.1181	0.0214	24

4. Conclusion

Risk identification is the first step in the supply chain risk management process. However, a very important task in risk management is to understand the relative importance of the identified risk and determine risks that have great adverse impact on supply chain performance. This helps firms to assign resources in a more efficient manner. The purpose of this paper was to help SMEs to efficiently involve in supply chain risk management process. By an almost appropriate review of the literature, 29 risks in the supply chain context identified that are classified under 6 main categories. Then, a CFPR method is proposed to determine the relative importance of identified risks. The results of the proposed method are presented in table 10.

As it is obvious form table 10, financial risk (0.2599), demand risk (0.1883) and supply risk (0.1815) are perceived to be the most important among risk sources. Among risk variables (sub-criteria level), exchange rate risk (0.0940), investment risk (0.0746), Forecast errors (0.0596) and Poor quality (0.0564) are perceived to be the most important. The paper provides several useful insights for SME managers. By identification and classification of risks, it provides useful information about supply chain risks. By prioritization of the identified risks, SME managers can

focus their resources more efficiently. It also It can also help firms to develop strategies to mitigate the adverse effects these risks.

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