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Information risks management in supply chains: an assessment and mitigation framework

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Abstract

Purpose – This paper aims to identify various information risks that could impact a supply chain, and develops a conceptual framework to quantify and mitigate them.

Design/methodology/approach – Graph theory has been used to quantify information risks while interpretive structural modelling (ISM) is employed to understand the interrelationships among the enablers of information risks mitigation.

Findings – The research presents a classification of the enablers of information risks mitigation according to their driving power and dependence. It also presents a risk index to quantify information risks. The research suggests that management should focus on improving the high driving power enabler variables.

Practical implications – The proposed risk index and the hierarchy-based model would help to develop suitable strategies to manage information risks in supply chains.

Originality/value – The major contribution of this paper lies in the development of a framework to quantify information risks and a hierarchy based model for their mitigation in context of supply chains.

Keywords Supply chain management, Information management, Risk management, Graph theory

Paper type Research paper

Introduction

Today business environment worldwide is experiencing a shift towards a knowledge-based economy where the performance of an enterprise depends much on the performance of its partners in the value chain. It has been recognised that high transactional cost will be involved if information cannot be effectively and efficiently communicated with customers externally and with suppliers internally (Choy *et al.*, 2004). Value in a supply chain is generated by lowering the firm's or partner's cost of sourcing or sales or increasing the service level. This can be achieved by using information technologies designed to manage complex information flows within or between firms (Biehl, 2005). Thus the 2000s are about the integration between enterprises and inter-enterprise processes with information technology tools particularly the internet playing the role of a major enabler (Kirchmer, 2004). The use of information technology to share data between buyers and suppliers has resulted in the growth of virtual supply chains (Yusuf *et al.*, 2004; Christopher, 2000). In a

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virtual supply chain the main driver would be information rather than the actual physical flow of goods.

Thus in recent time along with the physical supply chain, there is an emergence of information supply chain. This information sub-chain focuses on the management of information flows and represents a philosophy of managing technology and processes in such a way that the enterprise optimises the delivery of goods, services and information from the supplier to the customer (Búrca *et al.*, 2005). Thus supply chains can be viewed as an example of an IT-enabled inter-organisational configuration, where the coordination of logistics processes between organisations is the key to good performance (Lewis and Talalayevsky, 2004). Use of IT has facilitated the following major processes in a supply chain (Sabki *et al.*, 2004; Davenport and Brooks, 2004; Stockdale and Standing, 2004; Shore and Venkatachalam, 2003; Motwani *et al.*, 2000; Brandyberry and White, 1999):

- information sharing;
- better integration;
- access to global markets;
- global partnerships;
- changed production methods;
- improved customer service;
- enhanced collaboration;
- reduced transaction costs;
- product and service customisation;
- increased agility; and
- real time information capture.

So managing information in an inter-organisational context has become critical and the emergence of the internet and the range of related e-business technologies have created new opportunities and threats (Møller and ERP, 2005). Consequently the boundaries for evaluation and management of risk should extend beyond just the enterprise or company to include the risks that are inherited from the myriad of inter-organisational relationships that represent upstream and downstream trading partners in the supply chain, outsourcers, and other electronically connected business partners (Sutton, 2006). These threats require new approaches in the field of risk management. But research dealing with issues related to information risks from a supply chain perspective is almost negligible. The dynamics of the extended enterprise necessitates development of new models to understand these risks.

Today, the understanding about various information risks like virus, worms, and trojans has increased and organisations have become more cautious in their approach towards managing information. But the efforts to manage information risks generally focus within the organisational boundaries and are fragmented in their approach, while the increased stress to work on real time information facilitated by intranet, extranet demand new initiatives to manage these risks. In this context this research tries to address the issue of information risks as it relates to supply chains. This paper develops a new conceptual framework for mitigating and quantifying information risks in supply chains. To date, there has been limited research undertaken in this area and so the findings should provide an impetus for organisations to re-consider their approach to information risk management. Further, making use of interpretive structural modelling and graph theoretic approach the conceptual framework shows that to mitigate information risks there is a need to understand the mutual relationships among the enablers of risks mitigation and a suitable metric to quantify these risks.

Literature review

Developing a taxonomy of information risks in supply chains

Information technology (IT) and information systems (IS) are widely acknowledged as one of the major enablers of business change (Irani *et al.*, 2002). But the developments in information, computing and communication technologies together with the consequent erosion of entry and trading barriers represent factors, which have altered the commercial relationships fundamentally and simultaneously enhanced the risk exposure (Ritchie and Brindley, 2000). According to Aven *et al.* (2007) risk is the combination of the two basic dimensions: possible consequences and associated uncertainties. Thus the assessment and management of risks require both the probability of risky events and the losses to be understood and identified, and compared by applying a semi-quantitative scale (Hallikas *et al.*, 2004).

The focus of supply chain risk management (SCRM) is to understand, and try to avoid, the devastating ripple effects that disasters or even minor business disruptions can have in a supply chain (Norrman and Jansson, 2004). Speckman and Davis (2004) classifies risks in a supply chain into:

- physical dimension;
- informational dimension;
- financial dimension;
- security dimension;
- relationship dimension; and
- corporate social responsibility dimension.

Harland *et al.* (2003) provides a list of 11 categories of risks, but misses the information risks. Four basic approaches that a firm could employ to mitigate risks through a collaborative and coordinated mechanism are supply management, demand management, product management, and information management (Tang, 2006). Following this information risk can be defined as "the probability of loss arising because of incorrect, incomplete, or illegal access to information" and information risk management as "the management of information risks in supply chain through coordination or collaboration among the supply chain partners so as to ensure profitability and continuity". Risks associated with information have a wide variety of impacts. While the impact of information security/breakdown risks are very evident and immediate on supply chain operations, the impact of risk like intellectual property are not immediate but are critical for overall supply chain viability in the long term. So based on the type of impact that different information risks have on the supply chain, they can be broadly classified as:

- information security/breakdown risks;
- forecast risks;
- intellectual property rights risks; and
- IT/IS outsourcing risks.

Information security/breakdown risks

Information sharing among supply chain partners is the key to beat competition in the marketplace and so any breakdown or security breach in the information system would be critical for the whole network. Various losses associated with such events include immediate lost sales, emergency service cost, cost of restoring data, and long-term loss of customer goodwill (Cardinali, 1998). The financial consequences of information system failure make it necessary to develop a strong link between risk and cost-benefit analysis (Maguire, 2002).

Some common information security risks are:

- *Hackers, viruses and worms*. Viruses, worms and trojans are common menace to information systems. In a supply chain Tier II and Tier III level suppliers who are generally small and medium enterprises, are the ones most susceptible to such problems. Common reasons are non-availability of funds and lack of information security policy. Also as technology has made web an integral and necessary part of a business operation, hackers are using this technique to find confidential information which they use as backdoor entry into a company's innermost secrets (Ford and Ray, 2004).
- *Spyware*. It is a program that resides on computers linked to the internet and surreptitiously collects various types of personal information (Kucera *et al.*, 2005). So in a supply chain they may pose threat by illegal transfer of proprietary information.
- *Internal employee frauds*. This is one of the important information risks faced by organisations. Some of the common reasons are employee attrition, intentional/unintentional disclosure of proprietary information or in some cases personal vendetta against the company.
- *Distributed denial of services attacks*. The three most common categories of DDoS are bandwidth consumption, resource starvation, and resource exploitation (Zhang and Chen, 2005; Abouzakhar and Manson, 2002). These attacks interrupt legitimate access to the networks that may ultimately result in interruption to supply chain operations.
- *Natural disasters and terrorist attacks*. Tsunami, hurricanes (e.g. Katrina and Rita), fires or terrorist attacks like 9/11 have brought forth the importance of not only data backup but have made organisations to seriously think of mirror sites to keep the flow of information uninterrupted in a supply chain. Also the omnipresent internet technology could be leveraged by the terrorists to sieve contents of government web sites and find potential targets, identify or exploit weaknesses, obtain and integrate disparate information (Halchin, 2004).

Forecast risks

Forecast risks results from a mismatch between a company's projections and actual demand (Chopra and Sodhi, 2004). All kinds of information distortions in a supply chain, often lead to the forecast risks. It creates situations where the orders to the supplier tend to have larger fluctuations than sales to the customer. Major causes of information distortion are (Lee *et al.*, 1997):

- promotions and incentives that lead to forward buying;
- lack of knowledge of end-customer demand at upstream locations leading to inaccurate demand forecast updating;
- order batching leading to higher volatility in orders;
- price fluctuation; and
- rationing and shortage gaming.

To reduce the impacts of information distortion in supply chains concepts like "collaborative planning, forecasting and replenishment (CPFR)", "efficient consumer response (ECR)" and "vendor managed inventory (VMI)" are being implemented. Companies like Saturn, Dell, Whirlpool, and Wal-Mart are sharing information with suppliers and customers to decrease costs and improve customer service that helps in reducing forecast risks (Dennis and Kambil, 2003; Handfield and Nichols, 1999).

Intellectual property rights (IPR) risks

Intellectual property right (IPR) is a right given over a creation of the mind and to exclusively exploit it for a certain period of time. In a supply chain context ownership of knowledge and its legal use in cooperative development activities to make rapid innovations with quick diffusion to the market place and fair sharing of benefits will be the key means to success (Ganguli, 2000). With a growing trend for outsourcing non-core activities, risks associated with intellectual property have become important. In the last decade China and India has emerged as low cost destinations but these countries have a poor track record of IP protection. Also in many cases suppliers are serving competitors, aggravating the fears of proprietary information leakages in a supply chain. In a turbulent business environment customers have many choices available and thus intellectual property is the key to survival (whole of the software business survival lies on IP protection). Understanding and managing risks associated with intellectual property are important because:

- uniqueness of product/services defines a supply chain's position in the market;
- intellectual property creation is an investment intensive activity; and
- although it takes exhaustive efforts for creation, it can be easily replicated.

IT/IS outsourcing risks

Pervasive adoption of IT has made information technology outsourcing (ITO) a growing multi-billion dollar industry (Cullen *et al.*, 2005). IT outsourcing is broadly defined as a decision taken by an organisation to contract-out or sell the organisation's IT assets, people and/or activities to a third-party supplier, who in exchange provides and manages assets and services for monetary returns over an agreed time period (Kern and Willcocks, 2000). Bahli and Rivard (2005) have identified various risk factors associated with IT outsourcing and for each risk factor; measures were either identified in the literature or were developed. Advantages of IT/IS outsourcing include cost reduction, service quality improvement, access to state-of-the-art technology, and an increased ability to focus on the "core business". But along with the advantages, IT/IS outsourcing also brings with it several risks as summarised in Table I.

To reduce the risks associated within the context of large-scale single supplier outsourcing, approaches like "value-added" outsourcing whereby vendor and client combine their capabilities to market IT products and services; client and vendor taking equity holdings in each other; "co-sourcing", involving "performance-based" contracts; and the creation between the vendor and client of a "spin-off" company selling IT services on to the wider market are being practiced (Willcocks *et al.*, 1999).

Enablers of information risks mitigation

Mitigation of information risks requires collective efforts from supply chain partners. For reducing information risks in a supply chain, mutual trust for long-term relationships and the confidentiality of information among partners is a necessity (Kilpatrick and Factor, 2000). Lack of trust and dependence on outsourcing are two major reasons that contribute to supply chain risks (Sinha *et al.*, 2004). Information sharing that provides a shared basis for concerted actions by different functions across interdependent firms (Whipple *et al.*, 2002) is an important enabler of information risks mitigation. Where information is transparent there is a high level of trust and commitment (Christopher, 2000). Fisher (1997) indicates that supply chain collaboration leads to cohesive market focus, better coordination of sales and demand fulfilment, and minimum risks associated with forecasting. Information risks like system breakdown can be reduced by a reliable IT infrastructure that is not achievable without funds being available (Bender, 2000). Under these situations, the role of top management assumes significance (Kilpatrick and Factor, 2000). Lee *et al.* (2000) have analysed the benefits of sharing information on demands and/or inventory levels between suppliers and customers that helps to reduce forecast risks. This necessitates collaborative planning among supply chain members (Hoyt and Huq, 2000). Further the efficient management and operation of business processes like that in a supply chain are considered closely aligned with the development of a comprehensive IT/IS infrastructure (Sharif and Irani, 1999). The greater the degree of coupling or integration between the information systems of trading parties, the greater the degree of coordination and collaboration that can be achieved (White *et al.*, 2005). Supply chain partnership leads to increased information flows, reduced uncertainty, and a more profitable supply chain resulting in a higher quality, cost-effective product in a shorter amount of time (Fiala, 2005). Support to partners is facilitated by incentive

SN	IT/IS outsourcing risks	Contributors
1.	Opportunism of vendors	Barthélemy (2003)
2.	Information security apprehension	Khalfan (2004)
3.	Hidden costs	Collins and Millen (1995)
4.	Loss of control	Lacity and Hirschheim (1993)
5.	Service debasement	Bahli and Rivard (2005)
6.	Disagreements, disputes and litigations	Earl (1996)
7.	Poaching	Walden and Hoffman (2007)

Table I.
IT outsourcing risks

alignment that refers to the degree to which supply chain members share costs, risks, and benefits (Simatupang and Sridharan, 2004).

Research objectives

The focus of this paper is on information management, particularly on the mitigation aspect of various information risks that could impact the flow of information in a supply chain network. The major objective is to contribute and provide a better understanding of information risk management in supply chains.

The main research problems addressed by the study are:

(1) What information risks are associated with supply chains?

(2) What kind of interrelationships exits between these information risks?

(3) How can these risks be estimated?

Methodology

To address the above questions, a framework is proposed that integrates interpretive structural modelling (ISM) and graph theoretic approach. A brief discussion on the rationale for choosing these two approaches is presented followed by research design and data collection. Ill-defined problems tend to be dynamic problems that involve human factors. Soft systems methodology (SSM) is generally used for dealing ill-defined problems as to what shall be done, because at the onset there is no obvious or clearly defined objective. But the main limitation of SSM is that it can be used to solve only some ill-parts of the system and not for building the system as a whole (Ravi *et al.*, 2005). The structural equation modelling (SEM) is a confirmatory approach to data analysis requiring a priori assignment of inter-variable relationships. It tests a hypothesised model statistically to determine whether it is valid with the sample data (Schumacker and Lomax, 1996). One of the limitations of SEM is that it requires the statistical data to obtain results.

Information risks mitigation in a supply chain depends on a number of variables. A model depicting relationships among key variables would be of great value to the top management to delineate the focus areas. ISM can rightly be employed under such circumstances because on the basis of relationship between the variables, an overall structure can be extracted for the system under consideration. The ISM process transforms unclear, poorly articulated mental models of systems into visible, well-defined models useful for many purposes (Sage, 1977). Further, there is also a need to quantify information risks so that the management can understand the contribution of various classes of information risks and whether their efforts to mitigate these risks are yielding the desired results or not. The impact of information risks in a supply chain is dependent upon several sub-variables and thus the overall impact is the result of the individual impact of the sub-variables and their interrelationships. This dynamic behaviour of various information risks can be quantified with the help of graph theoretic approach. Thus an index that would quantify the information risks in a supply chain would be developed by extending the graph theory in the domain of information risk management in a supply chain.

Research design

Interpretive structural modelling. Interpretive structural modelling can be used for identifying and summarising relationships among specific variables, which define a problem or an issue (Sage, 1977; Warfield, 1974). It provides a means by which order can be imposed on the complexity of such variables. Researchers have applied ISM to analyse variety of systems (Faisal *et al.*, 2006a; Jharkharia and Shankar, 2005; Bolaños *et al.*, 2005). In ISM a set of different and directly related variables affecting the system under consideration is structured into a comprehensive systemic model. Therefore, in this paper, the enablers of information risks mitigation have been analysed using the ISM methodology, which shows the interrelationships of the enablers and their levels. These enablers are also categorised depending on their driving power and dependence.

The various steps involved in the ISM methodology are as follows:

- *Step 1*: variables affecting the system under consideration are listed, which can be objectives, actions, and individuals etc.
- *Step 2*: from the variables identified in step 1, a contextual relationship is established among variables with respect to which pairs of variables would be examined.
- *Step 3*: a structural self-interaction matrix (SSIM) is developed for variables, which indicates pairwise relationships among variables of the system under consideration.
- *Step 4*: reachability matrix is developed from the SSIM and the matrix is checked for transitivity. The transitivity of the contextual relation is a basic assumption made in ISM. It states that if a variable A is related to B and B is related to C, then A is necessarily related to C.
- *Step 5*: the reachability matrix obtained in step 4 is partitioned into different levels.
- *Step 6*: based on the relationships given above in the reachability matrix, a directed graph is drawn and the transitive links are removed.
- *Step 7*: the resultant digraph is converted into an ISM, by replacing variable nodes with statements.
- *Step 8*: the ISM model developed in step 7 is reviewed to check for conceptual inconsistency and necessary modifications are made.

Graph theoretic model. Graph theoretic approach considers the physical or abstract structure of a system explicitly or implicitly and can handle them conveniently. Graph/digraph model representation has proved to be useful for modelling and analysing various kinds of systems and problems in numerous fields of science and technology (Faisal *et al.*, 2006b; Rao and Padmanabhan, 2006; Chen, 1997). The graph theoretic methodology consists of the digraph representation, the matrix representation and the permanent function representation. While the digraph is the visual representation of the characteristics and their interdependencies, the matrix converts the digraph into mathematical form and the permanent function is a mathematical model that helps to determine index. Various steps of this approach are presented in Figure 1.

Data collection. For the purpose of identification of variables that facilitates the process of information risks mitigation in supply chains; four small and medium enterprises (SMEs) clusters were identified. These were brass cluster, lock cluster, leather cluster and the ceramic cluster. Majority of the companies in these four clusters

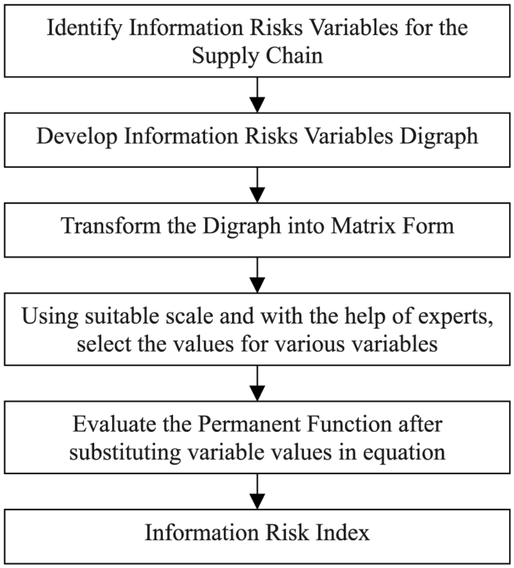

Figure 1.
Flow chart for graph theoretic approach

are sole proprietorships and family owned businesses. In each cluster enterprises that were the top ten export earners in the district industries centre exporters directory were selected. This criterion was deliberately chosen because these organisations are members of the supply chain that extends beyond the geographical boundaries of the nation and consequently depends largely on the flow of information to provide the right products in right quantities at the right place. In the first phase, an initial visit to the selected organisations was undertaken to understand their use of IT to manage supply chain operations. Further using semi-structured questionnaire technique, interviews were conducted. The personnel interviewed were in charge of the IT function in the selected organisations. One of the major findings was the fact that although these SMEs are in the process of integrating various IT enabled processes in their supply chains, few had a comprehensive information risks mitigation strategy in place. In the second phase a formal invitation was extended to these companies to nominate their representatives for the workshop. But from the selected organisations only 13 experts participated, while rest cited non-availability of time, lack of knowledge, and no expertise in IT function as the major reasons for non participation. To moderate the discussion two academicians working in the area of supply chain management also participated in the workshop.

Before the workshop, literature related to information risk management was posted to the participants to familiarise them with the formal categorisation of information risks as it relates to supply chains. Then in the brainstorming session participants were asked to identify and define enablers of information risks mitigation in the supply chain. After two brainstorming sessions fifteen enablers were agreed upon, which were finally reduced to 12 as some overlapped and some were combined. Then the experts were also asked to identify the mutual relationships among the variables. In the last session of the workshop a list of variables as identified and the diagram representing the mutual relationship was circulated among the participants for any modification.

With a consensus on these 12 variables among the experts they were used to develop the ISM based model. The selected variables are:

(1) Information sharing among supply chain (SC) partners.
(2) Supply chain wide strategies to mitigate information risks.
(3) Level of supply chain integration.
(4) Collaborative relationships among supply chain (SC) partners.
(5) Support to partners.
(6) Reliable IT/IS infrastructure.
(7) Top management commitment.
(8) Trust among supply chain (SC) partners.
(9) Awareness about information risks.
(10) Availability of funds to implement SC wide information risk mitigation strategies.
(11) Incentives alignment.
(12) Metrics for continual information risks assessment and analysis.

Analysis of interaction among the enablers of information risks mitigation

Structural self-interaction matrix

Contextual relationship of "leads to" type is chosen which means that one variable helps to achieve another variable. Based on this, contextual relationship between the variables as identified in data collection stage is developed. Keeping in mind the contextual relationship for each variable, the existence of a relation between any two enablers (i and j) and the associated direction of the relation is questioned. Four symbols are used to denote the direction of relationship between the enablers (i and j):

(1) V: enabler i will help to achieve enabler j.
(2) A: enabler i will be achieved by enabler j.
(3) X: enabler i and j will help achieve each other.
(4) O: enablers i and j are unrelated.

Based on the opinion of experts Table II is developed.

Reachability matrix

The SSIM is transformed into a binary matrix, called the initial reachability matrix by substituting V, A, X, O by 1 and 0 as per the case. The rules for the substitution of 1's and 0's are the following:

- If the (i, j) entry in the SSIM is V, then the (i, j) entry in the reachability matrix becomes 1 and the (j, i) entry becomes 0.
- If the (i, j) entry in the SSIM is A, then the (i, j) entry in the reachability matrix becomes 0 and the (j, i) entry becomes 1.
- If the (i, j) entry in the SSIM is X, then the (i, j) entry in the reachability matrix becomes 1 and the (j, i) entry also becomes 1.

Enablers	12	11	10	9	8	7	6	5	4	3	2
1. Information sharing	V	V	V	A	X	V	A	V	X	A	V
2. Supply chain wide strategies	V	X	V	A	A	X	A	V	A	A	
3. Level of supply chain integration	V	V	V	X	V	V	X	V	V		
4. Collaborative relationships	V	V	V	A	X	V	A	V			
5. Support to partners	V	A	A	A	A	A	A				
6. Reliable IT/IS infrastructure	O	O	V	X	O	O					
7. Top management commitment	V	V	V	A	A						
8. Trust among partners	V	V	V	A							
9. Awareness about information risks	V	V	V								
10. Availability of funds	V	A									
11. Incentives alignment	V										
12. Metrics for assessment and analysis											

Table II.
Structural self interaction matrix (SSIM)

- If the (*i, j*) entry in the SSIM is O, then the (*i, j*) entry in the reachability matrix becomes 0 and the (*j, i*) entry also becomes 0.

Following these rules and after incorporating transitivities final reachability matrix for the enablers is shown in Table III.

Level partitions
From the final reachability matrix, the reachability and antecedent set (Warfield, 1974) for each enabler are found. The reachability set consists of the element itself and the other elements that it may impact, whereas the antecedent set consists of the element itself and the other elements that may impact it. Thereafter, the intersection of these sets is derived for all the enablers. The enablers for whom the reachability and the intersection sets are the same occupy the top level in the ISM hierarchy. The top-level element in the hierarchy would not help achieve any other element above its own level. Once the top-level element is identified, it is separated out from the other elements. Then, the same process is repeated to find out the elements in the next level. This process is continued until the level of each element is found (Tables IV and V). These levels help in building the digraph and the final model.

Enablers	1	2	3	4	5	6	7	8	9	10	11	12	Driver
1. Information sharing	1	1	0	1	1	0	1	1	0	1	1	1	9
2. Supply chain wide strategies	0	1	0	0	1	0	0	0	0	1	1	1	5
3. Level of supply chain integration	1	1	1	1	1	1	1	1	1	1	1	1	12
4. Collaborative relationships	1	1	0	1	1	0	1	1	0	1	1	1	9
5. Support to partners	0	0	0	0	1	0	0	0	0	1	0	1	3
6. Reliable IT/IS infrastructure	1	1	1	1	1	1	1	1	1	1	1	1	12
7. Top management commitment	0	1	0	0	1	0	1	0	0	1	1	1	6
8. Trust among partners	1	1	0	1	1	0	1	1	0	1	1	1	9
9. Awareness about information risks	1	1	1	1	1	1	1	1	1	1	1	1	12
10. Availability of funds	0	0	0	0	1	0	0	0	0	1	0	1	3
11. Incentives alignment	0	1	0	0	1	0	0	0	0	1	1	1	5
12. Metrics for assessment and analysis	0	0	0	0	0	0	0	0	0	0	0	1	1
Dependence	6	9	3	6	11	3	8	6	3	11	9	12	

Table III.
Final reachability matrix

Enabler	Reachability set	Antecedent set	Intersection set	Level
1	1,2,4,5,7,8,10,11,12	1,3,4,6,8,9	1,4,8	
2	2,5,10,11,12	1,2,3,4,6,7,8,9,11	2,11	
3	1,2,3,4,5,7,8,9,10,11,12	3,6,9	3,6,9	
4	1,2,4,5,7,8,10,11,12	1,3,4,6,8,9	6,8,9	
5	5,10,12	1,2,3,4,5,6,7,8,9,10,11	5,10	
6	1,2,3,4,5,6,7,8,9,10,11,12	3,6,9	3,6,9	
7	2,5,7,10,11,12	1,3,4,6,7,8,9	7	
8	1,2,4,5,7,8,10,11,12	1,3,4,6,8,9	1,4,8	
9	1,2,3,4,5,6,7,8,9,10,11,12	3,6,9	3,6,9	
10	5,10,12	1,2,3,4,5,6,7,8,9,10,11	5,10	
11	2,5,10,11,12	1,2,3,4,6,7,8,9,11	2,11	
12	12	1,2,3,4,5,6,7,8,9,10,11,12	12	I

Table IV.
Iteration I

Iteration	Enabler	Reachability set	Antecedent set	Intersection set	Level
II	5	5,10	1,2,3,4,5,6,7,8,9,10,11	5,10	II
II	10	5,10	1,2,3,4,5,6,7,8,9,10,11	5,10	II
III	2	2,11	1,2,3,4,6,7,8,9,11	2,11	III
III	11	2,11	1,2,3,4,6,7,8,9,11	2,11	III
IV	7	7	1,3,4,6,7,8,9	7	IV
V	1	1,4,8	1,3,4,6,8,9	1,4,8	V
V	4	1,4,8	1,3,4,6,8,9	1,4,8	V
V	8	1,4,8	1,3,4,6,8,9	1,4,8	V
VI	3	3,6,9	3,6,9	3,6,9	VI
VI	6	3,6,9	3,6,9	3,6,9	VI
VI	9	3,6,9	3,6,9	3,6,9	VI

Table V.
Iteration II-iteration VI

Building the ISM model

From the final reachability matrix (Table III), the structural model is generated. If there is a relationship between the enablers i and j, this is shown by an arrow which points from i to j. This graph is called a directed graph, or digraph. After removing the transitivities the digraph is finally converted into the ISM-based model (Figure 2).

MICMAC analysis

The objective of MICMAC analysis (Faisal *et al.*, 2006a; Mandal and Deshmukh, 1994) in this study is to identify and to analyse the variables according to their driving power and dependence power towards information risks mitigation. Based on the driving power and the dependence, these enablers have been classified into four categories:

(1) Autonomous enablers.

(2) Dependent enablers.

(3) Linkage enablers.

(4) Independent enablers.

The driver power and dependence of each of these enablers is found from Table III and then a driver power-dependence diagram is constructed as shown in Figure 3.

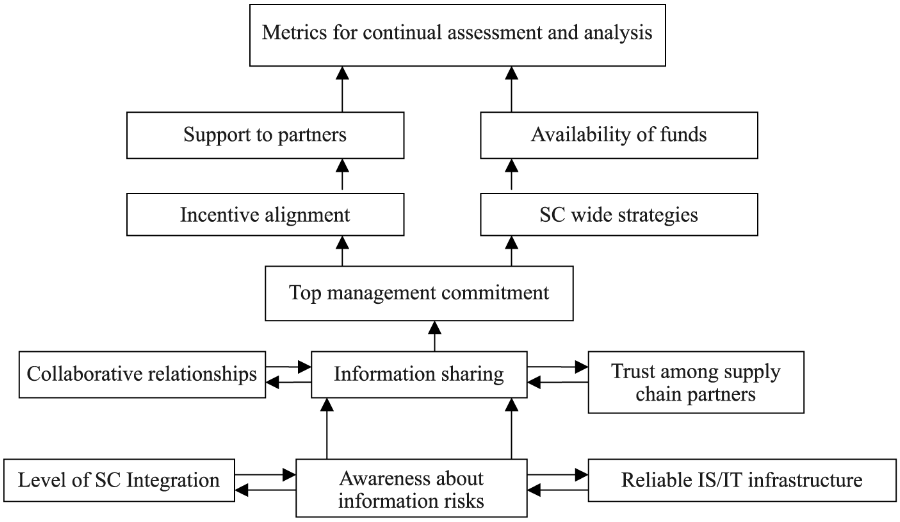

Figure 2.
ISM based model for information risk mitigation in a supply chain

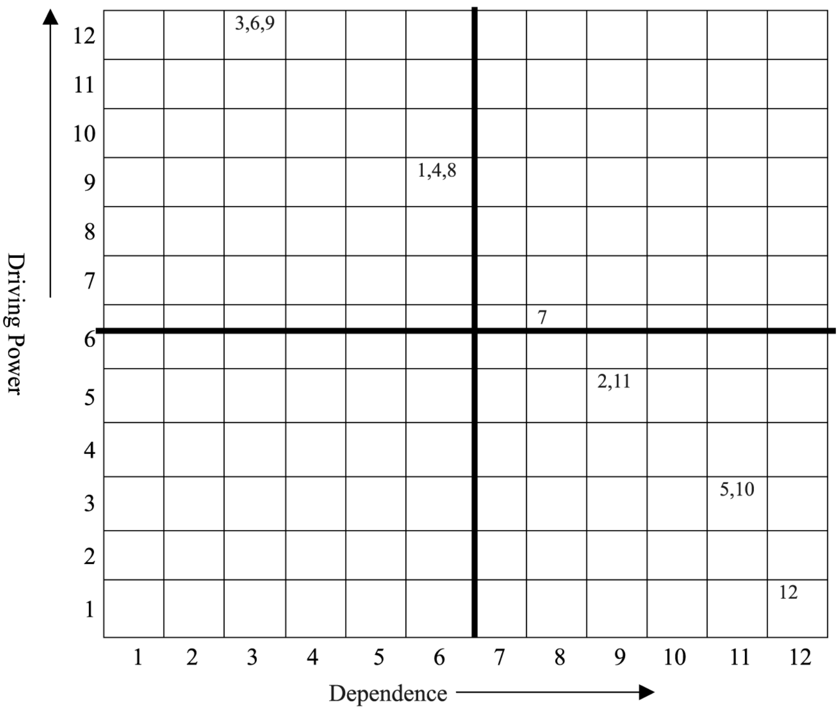

Figure 3.
Driver power and dependence diagram

In this classification, the first cluster includes “autonomous enablers” that have a weak driver power and weak dependence. These enablers are relatively disconnected from the system. In the present case, there is no autonomous enabler. The second cluster consists of the dependent variables that have weak driver power but strong dependence. In the present case, enablers 2, 11, 5, 10 and 12 are in the category of dependent variables. Enabler 12 has the maximum dependence, indicating that the effectiveness of any metric to evaluate the information risks is dependent on all the other variables. The third cluster includes linkage variables that have strong driver power and dependence. Any action on these variables will have an effect on the others above them and also a feedback effect on themselves. In this case, enabler 7 is the linkage variable that implies that all the enablers above this level would be impacted by this while it is dependent on lower level variables of the ISM model. The fourth cluster includes independent variables with strong driver power and weak dependence. In this case, enablers 1, 4, 8, 3, 6 and 9 fall in the category of driver enablers. But maximum driving power is for enablers 3, 6, 9. These are awareness about information risks, level of supply chain integration and reliable IS/IT infrastructure. These variables are the most important variables that influence the impact of other variables appearing at the top of the ISM hierarchy in the overall information risks mitigation process, implying that management needs to address these enabler variables more carefully in the supply chains.

Quantification of information risks

In the ISM model developed in the previous section the topmost enabler is the metrics for continual assessment and analysis of information risks. Measurement of information risks is important to understand their contribution to overall risk susceptibility of the supply chain, and also to determine the impact of the efforts to mitigate them. It would facilitate the process of devising suitable strategies to alleviate these information risks. To quantify information risks, graph theoretic approach would be employed through which individual contribution and the relative interdependencies among various categories of information risks can be captured.

Identification of system variables

Elements that are a potential information risk in a supply chain are identified. In this case following the information risks taxonomy the four variables are:

(1) Information security/breakdown risks (I_1).

(2) Forecast risks (I_2).

(3) Intellectual property rights risks (I_3).

(4) IS/IT outsourcing risks (I_3).

Develop the digraph

Digraph provides a graphical representation of the variables and their relative importance for a quick visual appraisal of the system under consideration. In a digraph a node represents information risk variable and edges represent the interrelationships among the variables. For developing the digraph representing information risks as a system, the four sub-systems considered are: information security/breakdown risks, forecast risks, intellectual property rights risks, and IT/IS outsourcing risks. These sub-systems may further have attributes, like IS outsourcing risks sub-system can have hidden costs, loss of control, service debasement as variables. Then each of the sub-system is analysed from the point of view of its attributes and then the next level for analysis is followed. But for the sake of simplicity the four sub-systems are considered as single variables impacting the information risks system. Digraph representing the four variables and their interdependencies is represented in Figure 4.

Transform the digraph into matrix form

Digraph is then transformed into matrix representation. The matrix would be $M \times M$ matrix where M is the number of variables considered. In this matrix the diagonal elements represents the inheritances, i.e. the impact of individual variables and off diagonal elements represents interdependencies or relative impacts. The digraph representing the four variables and their relative interdependencies as shown in Figure 4 is converted into a 4×4 matrix as per equation (1):

$$I^* = \begin{pmatrix} I_1 & i_{12} & i_{13} & 0 \\ 0 & I_2 & 0 & 0 \\ 0 & 0 & I_3 & 0 \\ i_{41} & 0 & i_{43} & I_4 \end{pmatrix} \quad (1)$$

Translate the matrix into permanent function

The permanent of this matrix I^*, i.e. per (I^*), is defined as the universal information risk function. Permanent is a standard matrix function and is used in combinatorial mathematics (Harary, 1985). It is a mathematical equation used to determine an index (Jense and Gutin, 2000). The permanent function does not contain any negative sign and thus no information is lost. Using this function, matrix would be transformed into an equation. For a 4×4 matrix permanent function is given by equation (2):

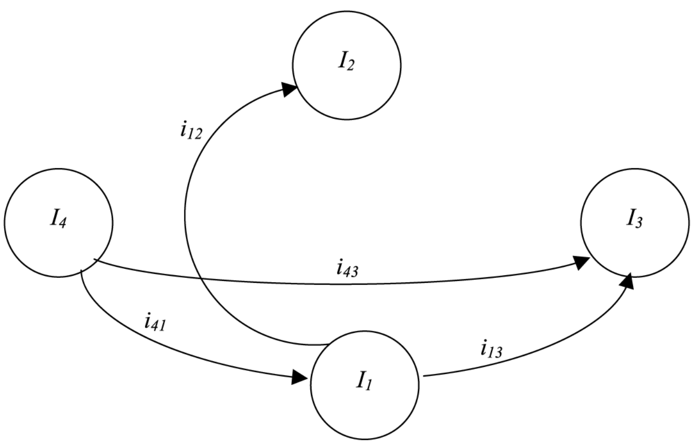

Figure 4.
Digraph representing the four information risks variables

$$Per(I^*) = \prod_{i=1}^{4} I_i + \sum_{1}\sum_{2}\sum_{3}\sum_{4}(i_{12}i_{21})I_3I_4 + \sum_{1}\sum_{2}\sum_{3}\sum_{4}(i_{12}i_{23}i_{31} + i_{13}i_{32}i_{21})I_4$$

$$+ \left\{ \sum_{1}\sum_{2}\sum_{3}\sum_{4}(i_{12}i_{21})(i_{34}i_{43}) + \sum_{1}\sum_{2}\sum_{3}\sum_{4}((i_{12}i_{23}i_{34}i_{41}) + (i_{14}i_{43}i_{32}i_{21})) \right\} \quad (2)$$

So for the system under consideration as represented by equation (1) the permanent function would be:

$$Per(I^*) = I_1I_2I_3I_4 \quad (3)$$

This equation can be termed as information risk index of the supply chain.

Substitute the values of the variables and obtain a single numerical index

To obtain the value of information risk index the values of inheritances (I_i) are required. These values can be obtained with the help of experts and in the absence of any quantitative data; a ranked value judgement on a suitable scale can be adopted.

Tabulate the results of the index and suggest suitable strategies

Values of information risk index can be used to assess information risks vulnerability of supply chains. Based on the values of the index, strategies to mitigate risks can be evolved. This approach quantifies the various variables making it simple to understand the deficient areas for effective information risks mitigation. Also information risk index can be used to compare supply chains working in different domains or for the same supply chain at different time periods.

Discussion

The importance of developing a robust and responsive information technology (IT) and information system (IS) infrastructure to support the formal planning and control of business processes is increasing in importance (Irani, 2002). Supply chain represents one such process where companies are constantly linked to their suppliers, distributors, third-party logistics service providers, financial providers, with whom they share up-to-date information (Bertolini *et al.*, 2004) and thus any accident or failure at any link is sure to have ripple effects in the overall supply chain. The ISM model developed in this paper provides the managers with an opportunity to understand the focal areas that needs attention to minimise the risks to the real time and free flow of information.

Though the capability of IT to reduce coordination and transaction costs and risks particularly related to bullwhip has been recognised (Lewis and Talalayevsky, 2004) management of risks associated with the information flow is yet become a part of overall strategy in supply chain management. So from a strategic perspective, this paper provides a comprehensive framework, which incorporates diversified issues related to information risks management in a supply chain. The framework suggested in the paper integrates graph theory and interpretive structural modelling which not only leads to a logical result, but also enables the decision-makers to quantify the impact of various variables of information risks in the final outcome.

As information visibility across the supply chain should be managed with strict policies, disciplines and monitoring (Búrca *et al.*, 2005), the information risk index that quantifies the various information risks is an effort in this direction. It would be a tool to monitor the supply chain's susceptibility to information risks. Also using this index supply chains can be benchmarked against the best practices in managing information and developing strategies to reduce the impacts of the disruptive events. In the wake of new risks because of integrated supply chains, organisations need to move beyond their organisational boundaries to assess the risks. The new approach requires the involvement of suppliers and sub-suppliers to identify, assess, and develop strategies to manage risks.

Information-based collaborative supply chains are emerging in industries as diverse as automobiles, grocery retailing and apparel manufacturing (Christopher and Lee, 2004) and the next phase would be actual system interoperability among suppliers, customers, and other business (Davenport and Brooks, 2004). ISM model delineates the areas like trust among supply chain partners, information sharing where collaborative efforts are required to mitigate information risks. This necessitates that all the partners understand their responsibility in the supply chain towards risks mitigation.

Lately the focus in the area of supply chain management is on concepts like adaptability, responsiveness, agility and leanness. These concepts depend to a large extent on real time information availability to all the partners. This makes the impacts of information failure more widespread. The models developed in this research gives opportunity to the management to quantify risks in lean or agile environments and develop suitable strategies to manage them.

Limitations and scope for future work

In the present study 12 variables were identified for modelling the information risk mitigation through ISM. More number of variables affecting information risks mitigation in a supply chain can be identified to develop ISM. Experts' help have been sought to develop the contextual relationships for the ISM model, which may have introduced some element of bias. Through ISM, a relationship model among information risks mitigation variables in a supply chain has been developed but this model is not statistically validated. In future extension of this work it is proposed to apply structural equation modelling (SEM) technique, commonly known as linear structural relationship approach to statistically corroborate the findings from ISM model. In the graph theoretic model, for the sake of simplicity the subsystems within these each system of risks were not considered. This is one of the major limitations in the development of information risk index. So in future work the subsystems may be considered and the impacts and interrelationships among the subsystem variables can be taken into account. Also the interrelationships among the variables as represented by the digraph are based on the opinion of experts that again may have some bias. Further the proposed index may be evaluated for case supply chains to understand its behaviour in actual practical settings.

Conclusions

This paper has presented an argument that to mitigate information risks; there is a need to understand the interrelationships among the enablers of risks mitigation. However, the research in the area of supply chain and information management is yet to formalise risks associated with information in a supply chain context. This has prompted the authors to identify and develop taxonomy of information risks that could impact a supply chain.

Risk management remains a complex management process, largely due to its dependency on a number of variables that are difficult to quantify in exact terms. The contribution of this paper is to construct an integrated framework for information risks mitigation and quantification. The framework will guide the supply chain and IT managers to understand and manage risks related to information in a supply chain. In this paper twelve variables were identified, which would help to mitigate information risks in supply chains. The awareness of these enablers and their driver and dependence power is important for information risks mitigation since management can now focus on those variables which are of more strategic orientation.

Along with the identification of enablers of risks mitigation this paper has also presented an approach to quantify information risks. This would help the decision-makers to estimate the impacts of various information risks and consequently develop suitable strategies to counter them. Therefore, to have a robust comprehensive information risks mitigation policy in place, it is necessary for supply chain and IT managers to not only understand various information risks mitigation variables but also the mutual relationships among them. The framework developed in this research has brought forth the following key issues:

- Variables like awareness about information risks, reliable IT/IS infrastructure and, level of supply chain integration have strong driver power and less dependency. Therefore, these are strong drivers and can be treated as the key enablers. They should be taken care on priority basis because there are a few other dependent variables being affected by them.
- The driver power-dependence diagram (Figure 3) indicates that there are no autonomous variables in the process of information risks mitigation in a supply chain. Autonomous variables are weak drivers and weak dependents and do not have much influence on the system. The absence of any autonomous variables (enablers) in this study indicates that all the considered enablers influence the process of information risks mitigation in a supply chain and management should pay attention to all the enablers.
- Overall impact of information risks in a supply chain is dependent on individual risks and their relative interdependencies. Thus, risk index represents the metric that can be effectively used to quantify information risks in supply chains.

At a time when information is a key resource for operating the supply chains and information risks and its mitigation ranks high on the agenda, this paper provides an insight into the various aspects of information risks in a supply chain. The proposed methodology serves as a guideline to the supply chain and information system personnel to manage information risks effectively.

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