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An integrated approach to supply chain risk analysis

Anna Corinna Cagliano*
Alberto De Marco
Sabrina Grimaldi
Carlo Rafele

Department of Management and Production Engineering
Politecnico di Torino
corso Duca degli Abruzzi 24
10129 Torino, Italy

* Corresponding author
Telephone: +39 0110907206
Fax: +39 0110907299
e-mail: anna.cagliano@polito.it

An integrated approach to supply chain risk analysis

Despite the increasing attention that supply chain risk management is receiving by both researchers and practitioners, companies still lack a risk culture. Moreover, risk management approaches either are too general or require pieces of information not regularly recorded by organisations.
This work develops a risk identification and analysis methodology that integrates widely adopted supply chain and risk management tools. In particular, process analysis is performed by means of the standard framework provided by the SCOR-Model, the risk identification and analysis tasks are accomplished by applying the Risk Breakdown Structure and the Risk Breakdown Matrix, and the effects of risk occurrence on activities are assessed by indicators that are already measured by companies in order to monitor their performances. In such a way, the framework contributes to increase companies' awareness and communication about risk, which are essential components of the management of modern supply chains.
A base case has been developed by applying the proposed approach to a hypothetical manufacturing supply chain.
An in-depth validation will be carried out to improve the methodology and further demonstrate its benefits and limitations. Future research will extend the framework to include the understanding of the multiple effects of risky events on different processes.

Keywords: risk management; supply chain; performance measurement

Word count: 7,895

1. Introduction

Risk management has been gaining considerable attention in the last ten years as an autonomous subject in the field of supply chain management (Macgillivray et al. 2007; Verbano and Venturini 2011). The Supply Chain Council defines supply chains as encompassing every effort involved in producing and delivering a final product. Such efforts include managing supply and demand, sourcing raw materials and parts, manufacturing and assembling, warehousing and inventory tracking, order entry and order management, and distribution across all channels and delivery to the customer (Lummus et al. 2001).

The relevance given to the risk topic is notably triggered by the frequency and intensity of catastrophes, disasters, and crises that seem to have increased on a global

scale (Coleman 2006). Supply chains operate in an unpredictable environment and several factors and trends contribute to the exposure to uncertainty. In recent years, almost all industries have faced fiercer competition and accelerated market globalisation resulting in the need for making intra-firm and inter-firm business processes more efficient and responsive. This is the context that has spawned current supply chain strategies such as outsourcing and offshoring large portions of manufacturing and R&D activities, sourcing in low-cost countries, reducing inventories, streamlining the supply base, and collaborating more intensively with other supply chain partners (Hult et al. 2004). Similar policies produce stronger inter-firm dependence together with longer and more complex supply chain setups and globe-spanning operations, thus exacerbating the vulnerability of supply chains to unexpected events (Tang 2006). 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 in the eyes of customers and suppliers (Hendricks and Singhal 2003; Cousins et al. 2004). Therefore, risk management should be a core issue in planning and control of any organisation (Finch 2004).

However, companies that understand the importance of supply chain risk often do not know where to start in order to tackle it (Kiser and Cantrell 2006). With this regard, literature takes a quite general perspective on supply chain uncertainties and provides a limited support about how to deal with them from a practical point of view (Blackhurst et al. 2005). Literature on risk presents a wide range of techniques but they have been scarcely adapted to the needs of supply chain management (Khan and Burnes 2007). Thus, tools to assess the exposure to supply chain risks as well as to support the creation of awareness about this issue are needed (Zsidisin et al. 2005).

Contributing to this field, an approach for identifying and analysing supply chain risk is developed. It integrates process mapping prepared through the Supply Chain Operations Reference Model (SCOR-Model), key performance indicators (KPIs) measuring the effects of the occurrence of risky events, and conventional risk management tools such as the Risk Breakdown Structure and the Risk Breakdown Matrix. Based on a standard process reference model and on KPIs commonly measured by companies, our framework aims to provide a guideline to risk management and, in this way, to promote corporate interest in this crucial aspect of supply chains.

The paper is organised as follows. Literature background is presented in Section 2. The developed method for supply chain risk identification and analysis is detailed in Section 3 and its application to a base case is described in Section 4. Finally, Section 5 discusses findings, limitations, and future research directions.

2. Literature background

Risk is an issue that has been extensively discussed in the last decades and several definitions have been put forward in literature, including both undesirable and desirable unexpected outcomes. Basically, risk takes into account two aspects: the uncertainty about and the severity of the consequences of an activity having a value for human beings (Aven and Renn 2009).

In the context of supply chain, risk has been usually defined by taking a negative perspective. Juttner (2005) addresses supply chain risk as anything that presents an impediment or a hazard to information, material, and product flows from original suppliers to the delivery of the final product to the ultimate end-users.

Supply chain risk management is the identification and management of risks affecting a supply network through a coordinated effort among supply chain members

to reduce vulnerability as a whole (Christopher et al. 2002). Supply chain risk management should be considered as a strategic activity because it impacts on operational, market, and financial performances of a firm (Narasimhan and Talluri 2009).

Risk management is usually divided into a number of stages: risk identification, risk analysis, and risk response and monitoring (International Standards Organisation 2009). Available literature in identification and analysis is reviewed below for the purpose of this research.

There are basically two kinds of approaches to supply chain risk identification. The first one relies on brainstorming. This technique makes use of in-depth interviews with experts in order to define possible risks as well as to investigate the relationships between their causes and effects (Hallikas et al. 2002; Sinha et al. 2004). For example, Hallikas and others (2002) apply such procedure in the electronics and metal supply chains to identify the following groups of risks: demand related factors and value chain positioning, delivery performance ability, financial factors, and pricing.

The second approach to supply chain risk identification is based on the development of taxonomies of risks and associated sources and manifestations. Many reported applications of this technique classify supply chain risks according to the material, information, and economic flows. Delays or poor quality of suppliers, production disruptions, inadequate inventory levels, and lack of capacity are some of the most frequently identified risks related to the flow of materials. The risks affecting computer systems and demand forecasts can be mentioned among those connected with the informational flow. Finally, issues related to receivables and supplier bankruptcies are the most popular economic risks. Some authors also look at risks that may manifest themselves in any of the three supply chain flows, such as those related

to intellectual property, security, opportunistic behaviours, social responsibility, natural disasters, political, regulatory, and market strategies, wars and terrorism (Chopra and Sodhi 2004; Spekman and Davis 2004; Lockamy III and McCormack 2010)

As far as supply chain risk analysis is concerned, it is usually performed by means of a number of qualitative, semi-quantitative, and quantitative methods.

Qualitative methods define levels of judgement for the probability of occurrence and the severity of impact of risky events based on different scales. Probability may be evaluated through scales made up of several levels, such as ‘rare’, ‘unlikely’, ‘likely’, and ‘almost certain’. In a similar way, the scale for the severity of impact may include either two levels, e.g. ‘severe’ and ‘light’, or three or more levels, such as ‘high’, ‘medium’, and ‘low’ or ‘negligible’, ‘minor’, ‘major’, and ‘severe’ (Sinha et al. 2004; Sheffi 2005). The levels of probability and impact can be combined together to estimate the degree of risk that is again measured by a qualitative scale, such as ‘low’, ‘medium’, ‘high’, and ‘very high’ (Norrman and Jansson 2004)

In a semi-quantitative evaluation the levels of judgment are replaced with numerical values. A scale ranging from 1 to 4 for the probability of occurrence may represent very unlikely, improbable, probable, and very probable events respectively and values from 1 to 4 for the severity of impact may indicate insignificant, minor, serious, and catastrophic influences of risky events respectively (Hallikas et al. 2002). Additionally, some authors determine the importance of risk factors by calculating a relative weight for each of them with approaches such as the Analytic Hierarchy Process (AHP) (Wu et al. 2006).

Finally, when a significant amount of past data is available, quantitative risk analysis may be performed by applying simulation methods, such as Montecarlo technique, Petri Nets, and Fault and Event Trees, to calculate the probability of occurrence and the impact of risky events (Kleindorfer and Saad 2005; Wu and Olson 2008; Tuncel and Alpan 2010).

The literature review reveals that most of the approaches for supply chain risk management either are limited to the identification of risk areas or face risk analysis by requiring a careful recording of past events and data in order to accurately evaluate the probability of occurrence of risky events as well as the related impact. Otherwise, only degrees of magnitude of these quantities can be defined through qualitative judgements. Also, the analysis of previous works highlights that few methodologies approach risk by assuming the supply chain processes as a reference framework.

In such a context, companies do recognise the need for more efforts to face uncertainty but find scarce codified procedures to tackle it, especially when a corporate risk culture is not established and a poor event reporting is in place (Zsidisin et al. 2000; Blackhurst et al. 2005). Also, the proliferation of risk management software packages, which are kinds of black boxes based on sophisticated probabilistic methods to quantify uncertainty, does not encourage the development of a deep understanding of the underlying structure of inter-dependencies between risk sources, risk occurrences, and effects (Tah and Carr 2001).

Therefore, there is a need for comprehensive methodologies that provide companies with accurate guidelines about how to deal with supply chain risk from a quantitative perspective without investing in information systems and human resources to gather a huge amount of additional past data that are usually not available from organisations. Approaches should focus on how risk influences single activities

of supply chain processes and should rely on well established managerial models and informational flows. In this way they are able to stimulate an easy understanding and communication of causes and effects of uncertainty. Communication is a complex, though vital, task contributing to enhance the level of maturity towards risk, which refers to the extent to which risk governance is defined, institutionalised, and controlled (Macgillivray et al. 2007; Smillie and Blissett 2010).

In order to address the discussed gap in supply chain risk, our work proposes a framework to integrate both risk identification and analysis in extensively applied supply chain management practices, like process mapping and performance measurement. This is based on data currently recorded by companies for purposes other than risk investigation. In particular, for each supply chain process of the SCOR-Model, risk sources are identified and connected to elementary activities through a standard framework. After that, the effects of risky events due to the defined sources are assessed by means of data taken from the performance measurement system of an organisation.

3. A new framework for supply chain risk identification and analysis

3.1 Aim and steps of the framework

Our approach to supply chain risk management is intended to deal with the entire risk escalation process (Hillson 2004; Hillson et al. 2006). Any risky event is triggered by an internal or external source (step 1) and evolves through an occurrence affecting an activity (step 2). A probability and an impact may be associated to such occurrence, which in turn brings consequences (step 3) usually in terms of time, cost, and quality variance against expected performance (Figure 1).

Figure 1. Risk escalation process (Adapted from Hillson 2004)

Based on the guidelines suggested by literature to manage the risk escalation process (Hauser 2003; Norrman and Jansson 2004; Kiser and Cantrell 2006), the present framework can be subsumed as composed of three steps:

- *Process mapping*: processes are analysed in order to understand in what parts of a supply chain risky events may occur. Such task is accomplished by applying a breakdown of activities based on the SCOR-Model (Supply Chain Council 2008). Process mapping according to the SCOR-Model allows to understand those supply chain structures responsible for risk occurrence and to relate sources of uncertainty, identified through common tools for risk investigation, to the associated process activities.
- *Risk identification*: identification and classification of main sources of risk (step 1 in Figure 1) for each SCOR process are performed using a standard breakdown structure decomposed into main kinds of risk in a supply chain. Risk sources are then linked to the activities where associated risky events may occur and the nature of such events is identified.
- *Risk analysis*: taking a broad perspective, risk may be seen as an uncertainty that may be in turn either a threat or an opportunity, depending if it affects a business either negatively or positively (Ward and Chapman 2003; Hillson 2004). In the risk analysis phase of our approach, performance indicators, assessing the effects (step 3 in Figure 1) of risk occurrence (step 2 in Figure 1) on activities, are selected according to the nature of the risky events identified in the previous step. These performance indicators are measured and compared against their associated target values. The analysis of discrepancies reveals whether risky events that happened benefitted or harmed the investigated

processes, in order to set proper actions to either exploit or mitigate their consequences. Such actions will become proactive measures in the next time bucket, being supply chain activities repetitive in nature.

The following sections detail the steps along with the present framework unfolds and present the foundations on which it is based.

3.2 SCOR-Model as the foundation of the framework

Our approach uses the SCOR-Model version 9.0 as the fundamental supply chain structure for the analysis of risk. This model describes all the business activities associated with satisfying customer demand, in order to address, improve, and communicate supply chain management practices within and between the supply chain partners, from the sub-supplier to the client's customer. The SCOR-Model is organised around the five main supply chain processes, namely Plan, Source, Make, Deliver, and Return. Each of these five processes (SCOR Level 1) is in turn decomposed into sub-processes (SCOR Level 2) according to three process categories: Planning, Execution, and Enable. Each sub-process is divided into elementary activities (SCOR Level 3) for which inputs, outputs, best practices, and performance indicators are defined. In particular, the SCOR-Model provides a rich catalogue of key indicators to measure the performance of supply chain operations.

The SCOR-Model version 9.0 also incorporates supply chain risk assessment, tracking, and mitigation through the suggestion of risk management activities as well as best practices and performance metrics.

The SCOR-Model has been chosen as the foundation for the proposed risk management framework because it is a widely applied supply chain management tool (Stephens 2001; Huang et al. 2005). Moreover, the SCOR-Model has been recognised as being a valuable means to provide incentive alignment and collaboration for risk

avoidance and reduction by promoting cooperation among supply chain partners (Kleindorfer and Saad 2005; Srividhya and Jayaraman 2007). For example, the SCOR-Model has been adopted in the aerospace industry to integrate planning activities with the purpose of overcoming uncertainty and conflicting objectives and stimulating coordination among supply chain members (Raj and Whitman 2004).

The three pillars of the SCOR-Model, namely process modelling, performance measurement, and best practices, allow to take a systemic perspective, which is strongly needed given the all-embracing, multidimensional, and complex nature of risk (Le Coze et al. 2006). First, the SCOR-Model provides a process modelling ensuring that all the significant activities within a supply chain are identified, thus building a reliable basis for a comprehensive definition of risks. The standard structure provided by the SCOR-Model also makes all decision makers agree on processes and goals, which is of paramount importance to the establishment of a risk measurement system (Gaudenzi and Borghesi 2006). Second, the key performance indicators suggested by the SCOR-Model enable to evaluate the behaviour of different supply chain activities when exposed to risk. Third, the best practices presented by this model may support the identification of successful actions to either exploit or mitigate the risks detected by our approach.

3.3 Supply chain process mapping

To identify activities that might be affected by risk is the first step in every risk management methodology. In fact, a coherent representation of the supply chain structure is essential to express how different risks are related to the components of this structure (Narasimhan and Talluri 2009). Moreover, it makes companies more conscious of their business processes and assures proper actions to reduce the exposure to vulnerability (Braunscheidel and Suresh 2009).

Our framework suggests using the Activity Breakdown Structure (ABS) to map supply chain processes. The ABS comes from the Work Breakdown Structure (WBS) (Project Management Institute 2001) and is a hierarchical grouping of activities that organises and defines the scope of a process. Each descending level constitutes a more detailed decomposition of process tasks.

The ABS has been selected because it does not only decompose activities in a clear way but it is also able to properly represent the SCOR-Model structure. As a matter of fact, the SCOR-Model provides a three-level hierarchical structure defining the business activities associated with the fundamental supply chain processes, and each descending level depicts an increasingly detailed description of such activities.

Taking advantage of such similarity between the ABS and the SCOR-Model, our methodology performs risk identification by using ABSs based on the process breakdown provided by the SCOR-Model. The bottom level ABS elements are represented by SCOR third level elementary activities (Table A.1 in the Appendix).

3.4 Supply chain risk identification

To identify and classify risks according to their nature is an essential task before performing risk analysis and developing control strategies (Narasimhan and Talluri 2009). An accurate understanding of types of supply chain risks enables tailoring risk reduction approaches to the specific characteristics of each single organisation (Chopra and Sodhi 2004).

In our framework, once the activities of a supply chain process have been classified into an ABS, sources of risk for each lowest level activity should be identified and arranged to provide a standard representation of risk exposure facilitating understanding, communication, and management. This can be accomplished by adopting the Risk Breakdown Structure (RBS). The RBS is a

hierarchical, source-oriented grouping of risks that organises and defines the total risk exposure. Each descending level represents an increasingly detailed definition of sources of risk (Hillson 2002; Project Management Institute 2009). The RBS tool is chosen because it provides an effective foundation for a stratified classification of risks and the associated nomenclature (Tah and Carr 2001).

In our methodology, the RBS does not only serve as a framework for organising selected risk sources, but also supports their identification. Main literature about supply chain risk management is reviewed in order to build a general taxonomy that can be customised according to the process at issue. The RBS levels are intended to provide a prompt list of areas of risk affecting supply chain processes that guides the identification of risk sources impacting on specific activities. Table 1 illustrates the standard RBS frame; more levels may be added as needed.

Table 1. RBS frame for supply chain risk

Sources of supply chain risks are first categorised as external and internal ones (Smallman 1996; Kiser and Cantrell 2006). External risk sources cannot be controlled by a company, being exposed to its external environment. On the contrary, internal risk sources can be better handled because they are associated with decisions made and actions undertaken within the company. RBS Level 2 and Level 3 represent the most common determinants of supply chain risk reported by literature. Internal risk sources are structured according to the supply chain activity levels where risky events may occur. To this end, the three levels defined by the Global Supply Chain Forum (Lambert 2008), namely Strategic, Tactical, and Operational, are adopted. Detailed internal risk sources (Level 3) cannot be defined in this general RBS because they strongly depend on the specific kind of process under study.

The risk identification phase is completed by connecting detailed risk sources for each supply chain process with the corresponding elementary activities (SCOR-Model Level 3). The joint analysis of supply chain activities and risk sources increases risk visibility, which in turn may contribute to improve performance (Narasimhan and Talluri 2009).

For this purpose, activities at the lowest ABS level are the rows of a matrix, whose columns represent risk sources at the lowest RBS level. A Risk Breakdown Matrix (RBM) (Hillson 2004; Hillson et al. 2006) is thus generated; its cells identify the impacts of risk sources on activities. Figure 2 shows a RBM where the impacts of risk sources on activities are represented by colouring the corresponding cells. For example, in this RBM the risky events caused by the source R2.1 affect the activity A1.1, therefore the cell at the intersection between the risk source R2.1 and the activity A1.1 appears grey coloured.

Figure 2. Impacts of risk sources on activities in a RBM (Adapted from Hillson 2004)

After identification, it is necessary to investigate the nature of risk occurrence for each marked RBM cell: what kind of risky events caused by a source may affect the associated activity? And what are the related effects, such as time delays, quality issues, raw material shortages, etc.? This knowledge will guide the selection of performance indicators during the analysis phase. Such task is of paramount importance for choosing KPIs able to properly reflect risk effects and requires the understanding of supply chain processes provided by the first step of the approach.

3.5 Supply chain risk analysis

The risk analysis phase of the developed methodology focuses on the effects on activities of the occurrence of risky events due to the identified sources and estimates these effects through performance measurement.

In many companies, the availability of data about risk probabilities, impacts, and effects is scarce and they do not appear to be collected systematically. In some cases, managers estimate such quantities by means of subjective judgements, and this task may be difficult especially when events have not occurred before (Harland et al. 2003). Therefore, the value of risk, obtained as a multiplication of probability and impact, is not always easy to use and is not often understandable to business people (Norrman and Jansson 2004). To this end, performance indicators provide a reliable basis to estimate the probability and the impact of risky events as well as their effects through quantities that are specific to each organisation and can be easily controlled. The identification of good indicators supports effective risk management in any sector (Agnew et al. 2006) because, coupled with an accurate monitoring process, they may control any deviation from foreseen plans (Badr and Stephan 2007). Risk metrics may be either causal variables or proxies for the risk drivers and the associated consequences. They may either be monitored independently, in order to analyse single risks, or be considered as a system, in order to have a picture of the overall risk exposure of the business (Scandizzo 2005). The assessment of risk does not require a new set of KPIs, but rather a risk-adjusted view of the performance metrics already in place (Hauser 2003).

In our methodology, the indicators that are most capable to reflect the effects of risks (step 3 in Figure 1) are selected from corporate dashboards, to form a measurement system that aims to analyse the consequences of the occurrence of risky

events (step 2 in Figure 1) on supply chain activities, given their importance to properly control disruptions and other kinds of uncertainty (Scandizzo 2005). These consequences become manifest in supply chain outcome measures, such as those related to cost or quality, and, in general, in all those variables expressing a variance from expected performance. Literature provides comprehensive lists of such measures, ranging from financial through reputational, to safety-related ones (Goldberg et al. 1999; Harland and Brenchley 2001).

For each RBM cell where an impact of a risk source on an activity is defined, the occurrence of a risky event due to the source changes the performance of the activity in some way. Therefore, a KPI capturing such change is able to assess the degree of the effect of the risk occurrence on the activity, and it indirectly gives a knowledge about such occurrence that may be useful for future evaluations of the existing risks for each activity. To this end, KPIs are selected according to the nature of risky events and of their effects and placed into RBM cells.

The primary effects of risk on the processes where it occurs are assessed, thus providing a good trade-off between accuracy and speed in the risk management process (Zsidisin et al. 2004). As a matter of fact, performance indicators allow a quick but clear understanding of what supply chain areas need more attention and enable to prioritise those risks requiring a deeper investigation by acquiring additional pieces of information.

The analysis of any discrepancy of the actual performance against the target KPIs allows to investigate on either the negative or the positive nature of risky events to activate subsequent actions directed to either mitigate the effects of a threat or exploit the benefits of an opportunity.

4. Applying the framework to a manufacturing supply chain

The present section describes the application of the proposed framework for risk identification and analysis to a hypothetical internal supply chain of a manufacturing company.

In order to focus on a manageable case, we analyse the supply chain activities included in the SCOR-Model part dealing with Make-to-Order products. Moreover, risk sources are drawn from literature and performance metrics are selected from the SCOR-Model catalogue giving particular attention to the two most important aspects of customer requirements: timely delivery and product quality (Svensson 2004).

Source, Make, and Deliver processes of the SCOR-Model are studied. For each of them, most relevant sub-processes belonging to all the three Level 2 process categories are considered. In turn, most significant elementary activities for each of these sub-processes are selected. As an example, the ABS for the Source process is detailed in the Appendix (Table A.1). P2 Plan Source, S2 Source Make-to-Order Product, and ES Enable Source are the SCOR Level 2 sub-processes that are taken into account. The ABSs for Make and Deliver processes have been developed in a similar way.

The RBS that identifies the risk sources impacting on the Source process is shown in Table A.2 of the Appendix. It has been worked out by adapting the general RBS frame presented in Table 1 to take into account Level 3 risk sources specific for the process at issue. The last column of the RBS in Table A.2 reports literature sources not included in the review presented in Table 1. The RBSs classifying the risk sources affecting the Make and Deliver processes have been defined in the same way as for the Source process and are presented in Table A.3 and Table A.4 of the Appendix respectively.

For the purpose of preparing the RBMs, ABSs for the Source, Make, and Deliver processes are linked to associated RBSs. As an example, Table 2 presents the complete RBM for the Source process with the identification of the impacts of risk sources on activities (grey cells). All the RBMs for this case study, together with the ABSs and the RBSs, are available from the authors.

The possible risk occurrences are investigated for each impact defined in the RBM, together with the related effects on activities. According to the nature of both the risky events that may happen and their effects, KPIs enabling to measure the degree of such effects are selected. Performance indicators are coded according to the activity they refer to and how many different metrics have been associated with this activity. For example, the indicator SI2.4.1 defines the first KPI selected for the Source activity S2.4.

The analysis of some of the RBM cells of the three supply chain processes studied in this base case is presented below.

As far as the RBM for the Source process is concerned (Table 3), the risk source IS.5 *Machine performance during transiting of the sourced products* impacts on both the activity S2.2 *Receive Product* and the activity S2.4 *Transfer Product*. The identified risk occurrence is an incorrect functioning of the material handling equipment while either downloading the sourced products from trucks and moving them to the incoming raw material area or transporting them from that area to the manufacturing department. The main effects are delays in making such materials available for undergoing the production process and physical damages to the incoming products. On this basis, the effect on the activity S2.2 is measured by the KPI SI2.2 *% Orders/lines received damage free*, which assesses the number of orders or lines that are received damage free divided by the total orders or lines received in

the measurement period. In this case, only damages due to the material handling equipment used by the focus company are considered. The effect of risk occurrence on the activity S2.4 is measured by the indicators SI2.4.1 *%Product transferred on-time to demand requirement* and SI2.4.2 *% Product transferred damage free*. The first one evaluates the number of product orders or lines that are transferred to the manufacturing department on time divided by the total orders or lines transferred in the measurement period. The second one assesses the number of product orders or lines that are transferred to the manufacturing department damage free divided by the total orders or lines processed in the measurement period.

As far as the RBM for the Make process is concerned (Table 4), the risk source IM.7 *Machine performance* impacts on both the activity M2.3 *Produce and Test* and the activity M2.4 *Package*. In the first case, the identified risk occurrence is a poor performance of the production lines that could give as effects either a total manufacturing lead time longer than its standard value, because for example workstations take longer to perform their operations, or an increase in the number of defective products out of the line that have to be discarded. The following three metrics have been chosen to evaluate these effects: MI2.3.1 *Scrap expense,* MI2.3.2 *Total build cycle time*, and MI2.3.3 *Yield*. Scrap expense assesses the costs incurred in the measurement period from finished products falling outside of specifications and possessing characteristics that make rework impractical. Total build cycle time is defined as the time necessary to transform raw materials into finished products. Yield is the ratio of usable output from a production process to the amount of input in the measurement period, as a result of the finished product quality test. In the second case the risk occurrence is represented by a poor performance of the machines packaging the finished products to be delivered. The effect is packages not compliant with set

quality standards and is measured by the KPI MI2.4 *Scrap packaging expense*, which is defined as the costs incurred in the measurement period from dealing with packages falling outside of specifications.

Finally, the RBM for the Deliver process (Table 5) defines an impact of the risk source EXD.1 *Nature disasters* on the activity D2.12 *Ship Product* and an impact of the same source on the activity D2.13 *Receive and Verify Product by Customer*. In both the cases the risk occurrence is represented by natural events such as floods and hurricanes. On the one hand, the main effect of these risky events on the activity D2.12 is a delay in delivering the finished products to the customer. Thus, the KPI DI2.12 *Delivery performance to customer commit date* is chosen to measure such effect. This metric assesses the percentage of orders in the measurement period that are fulfilled on or before the original scheduled date. On the other hand, the effect of natural events on the activity D2.13 is receiving a relevant quantity of products that have been damaged during the transportation, and the KPI DI2.13 *Perfect order fulfilment* is selected to measure this effect. Here the Perfect order fulfilment evaluates the consignment compliance to the committed quality.

Table 2. Complete RBM for the Source process

Table 3. Portion of RBM for the Source process

Table 4. Portion of RBM for the Make process

Table 5. Portion of RBM for the Deliver process

The defined performance indicators should be then evaluated and compared with the associated target values in order to assess the degree of the effects of the occurrence

of risky events on supply chain activities. Threats and benefits originated by these events should be identified with the aim of supporting appropriate decision making.

5. Discussion

The developed framework for risk identification and analysis is grounded on the standard categorisation of supply chain processes offered by the SCOR-Model, thus making clear ‘what’ risk management is applied to.

Risk identification is not completely left to the experience and knowledge of process experts, but it is guided by a standard RBS frame that presents a comprehensive, literature driven catalogue of possible risk sources affecting supply chain operations. Such taxonomy ensures that any possible gaps or blind spots in risk identification are avoided, and all potential sources of risk are considered.

In addition, the Risk Breakdown Structure and the Risk Breakdown Matrix are simple but powerful risk management tools because they allow a systemic representation of both risk sources and their impacts on activities. The systemic perspective is also guaranteed by two other characteristics of our framework. First, it analyses both positive and negative implications of risk occurrence and covers all the phases of the risk escalation process. In fact, sources of risk are identified by means of the RBS, risk occurrence is investigated by the RBM for each supply chain activity, and effect analysis is performed by evaluating KPIs (Figure 3). Second, the proposed approach focuses on both processes and outcomes (Agnew et al. 2006) by simultaneously addressing the supply chain system, through process mapping and risk identification, and the results of single activities as measured by KPIs in the risk analysis phase.

Figure 3. Mapping the framework on the risk escalation process

The framework is also extremely flexible because it may be applied to various levels of organisational complexity, in order either to analyse just one supply chain process or to understand risks affecting all the main processes of a company, according to the amount of available information. Moreover, different breakdown structures of supply chain processes may be used as an alternative to the SCOR-Model one.

A key point of this approach is that the estimate of the risk effect by means of available performance measurement systems enables to quantify risk without the need for recording a great amount of additional past data. Furthermore, it enhances the value of performance measurement because it associates KPIs not only with activities but also with the related risk sources.

Therefore, the integration among process and risk management tools already existing in literature and implemented in practice facilitates a constant and purposeful application of the methodology by a large variety of manufacturing and service industries.

Also, the use of the SCOR-Model, the RBS, the RBM, and KPIs enhances the value of the Supply Chain Council model by supporting the implementation of the actions the SCOR-Model recommends for dealing with supply chain risk.

The value of this framework is that it may serve as a mean to increase communications on supply chain risk, a field where responsibilities are interdependent and a regular, cross-functional and multidirectional information sharing is required among people, who are the most important enabler of an effective risk management system (Elkins et al. 2005). In such a way, the proposed methodology contributes to promote a culture of risk awareness by providing managers and employees with a detailed and formalised procedure to handle uncertainty. When the level of maturity towards risk is high enough to enable a systematic tracking of risk data, the

framework developed in this work may also replace performance indicators with accurate numerical values of risk exposure. In addition, it could be implemented through an online IT system in order to improve information sharing among the stakeholders involved (Smillie and Blissett 2010).

5.1 Limitations and future research

The proposed methodology is mainly focused on observing the consequences of risks and does not quantify the probabilities of occurrence and the impacts. Furthermore, it does not analyse whether the risk occurrence has secondary effects on multiple processes. Finally, an extensive validation of the approach by applying it to multiple supply chain settings is required in order to uncover its potential weaknesses and foster refinements.

These limitations bring two future research lines. First, the methodology could be extended to analyse risk not only after its occurrence but also before it, by calculating probabilities of occurrence and impacts of risky events.

Second, the investigation of the cause and effect relationships among the monitored KPIs could be integrated in our framework as a way to trace how the effects of risk occurrence spread through multiple activities and processes, for instance from the Source process through the Deliver one.

6. Summary

This work presents a risk identification and analysis methodology that integrates well established supply chain and risk management tools, such as the SCOR-Model, the Risk Breakdown Structure, the Risk Breakdown Matrix, and performance indicators. The main purpose of the framework is increasing corporate awareness on supply chain risk by providing a structured approach to identify, assess, and communicate

sources and consequences of risky events. A base case has been developed by applying the proposed approach to a hypothetical manufacturing supply chain.

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Appendix

Table A.1. ABS for the Source Process

Table A.2. RBS for the Source Process

Table A.3. RBS for the Make process

Table A.4. RBS for the Deliver process

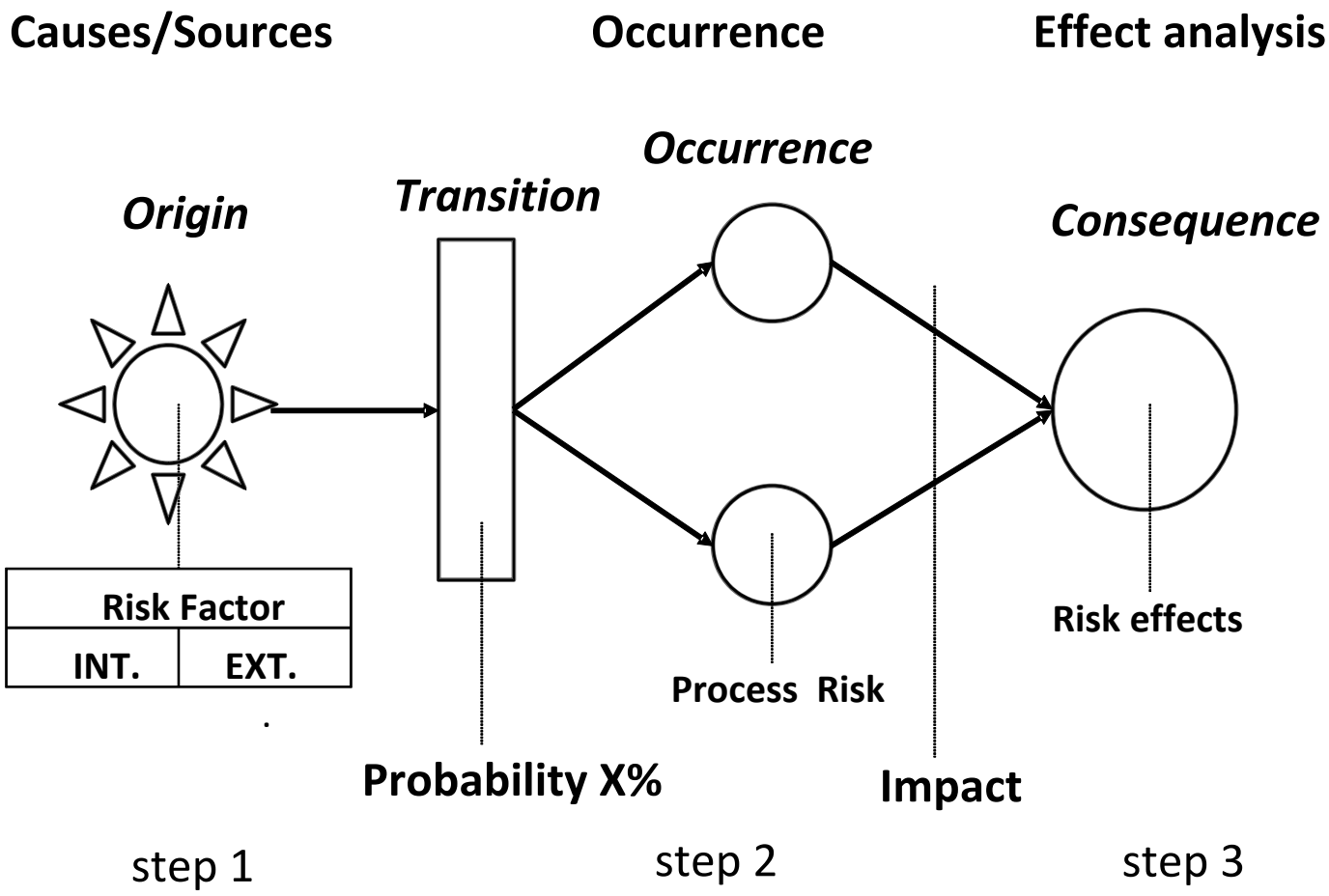

Causes/Sources
Occurrence
Effect analysis
Origin
Transition
Occurrence
Consequence
Risk Factor
INT.
EXT.
Risk effects
Process Risk
Probability X%
Impact
step 1
step 2
step 3

Figure 1

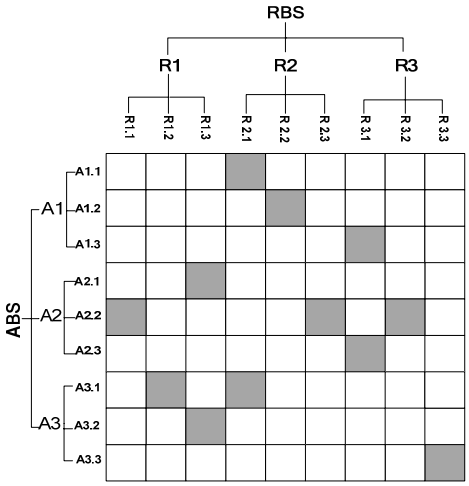

RBS
R1
R2
R3
R1.1
R1.2
R1.3
R2.1
R2.2
R2.3
R3.1
R3.2
R3.3
ABS
A1
A2
A3
A1.1
A1.2
A1.3
A2.1
A2.2
A2.3
A3.1
A3.2
A3.3

Figure 2

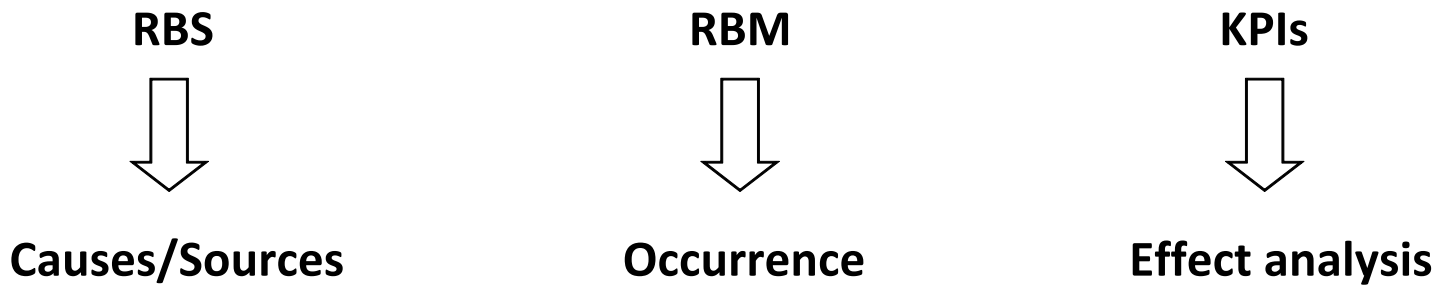


Figure 3

Table 1. RBS frame for supply chain risk

Level 0	Level 1	Level 2	Level 3	Literature Source
Standard RBS for supply chain processes	External	Catastrophic	Nature disasters	Kleindorfer and Saad 2005; Faisal et al. 2006; Kiser and Cantrell 2006; Goh et al. 2007; Khan and Burnes 2007
			Man-made accidents	
		Political	Changes in government policies	Kleindorfer and Saad 2005; Sheffi and Rice 2005; Khan and Burnes 2007
		Economic	Fuel price fluctuation	Wagner and Bode 2006; Ritchie and Brindley 2007; Ji and Zhu 2008
			Exchange rate fluctuation	
			Changes in the economic situation	
		Social	Labour strikes	Juttner 2005; Tang 2006; Braunscheidel and Suresh 2009
			Changes in the network of transportation hubs	
			IT system functioning	
		Legal	Changes in import/export regulations	Zsidisin et al. 2000; Kiser and Cantrell 2006
			Tariff changes	
		Cultural	Different culture	Wu et al. 2006; Manuj and Mentzer

				2008
		Industrial	Market price of resources changes	Oke and Gopalakrishnan 2009
			Production technological changes	
			Product design changes	
		Partner	Events related to suppliers, customers or retailers	Zsidisin et al. 2000; Chopra and Sodhi 2004; Spekman and Davis 2004
	Internal	Strategic	Depending on the process at issue	Lambert 2008
		Tactical		
		Operational		

Table 2. Complete RBM for the Source process

		Risk sources (RBS)																						
		EXS .1	EXS .2	EXS. 3	EXS. 4	EXS .5	EXS .6	EXS .7	EXS. 8	EXS. 9	EXS. 10	EXS. 11	EXS. 12	EXS. 13	EXS. 14	EXS. 15	EXS. 16	EXS. 17	EXS .18	IS.1	IS.2	IS.3	IS.4	IS.5	IS.6
Activities (ABS)	P2.1								■				■	■						■					
	P2.2								■			■								■					
	P2.3								■			■	■	■			■	■	■	■					
	P2.4			■	■	■		■		■	■	■			■		■	■	■	■					
	S2.2	■	■				■		■											■				■	■
	S2.3	■	■				■		■							■				■					
	S2.4						■		■											■				■	■
	ES.2	■	■						■		■	■	■	■	■	■	■	■	■	■		■			
	ES.3								■											■	■				
	ES.4	■	■		■	■					■	■	■	■	■	■	■	■	■	■			■		
	ES.5	■	■																		■				
	ES.6	■	■				■	■												■					
	ES.7			■	■	■		■			■	■	■	■	■		■	■	■	■		■			
	ES.8									■															
	ES.10											■	■	■	■	■	■	■	■	■					

Table 3. Portion of RBM for the Source process

Source RBM	**RBS**	
	Internal	
	Operational	
ABS	IS.5 Machine performance during transiting of the sourced products	IS.6 Operator's operations during transiting of the sourced products
S2: Source Make-to-Order Product		
S2.2 Receive Product	SI2.2 % Orders / lines received damage free	SI2.2 % Orders / lines received damage free
S2.3 Verify Product		
S2.4 Transfer Product	SI2.4.1 % Product transferred on-time to demand requirement SI2.4.2 % Product transferred damage free	SI2.4.1 % Product transferred on-time to demand requirement SI2.4.2 % Product transferred damage free

Table 4. Portion of RBM for the Make process

Make RBM	**RBS**			
	Internal			
	Operational			
ABS	IM.6 Production scheduling	IM.7 Machine performance	IM.8 Operator's operations	IM.9 Production process
M2: Make-to-Order				
M2.2 Issue Product	MI2.2 Inventory accuracy			
M2.3 Produce and Test		MI2.3.1 Scrap expense MI2.3.2 Total build cycle time MI2.3.3 Yield	MI2.3.1 Scrap expense MI2.3.2 Total build cycle time MI2.3.3 Yield	MI2.3.1 Scrap expense MI2.3.2 Total build cycle time MI2.3.3 Yield
M2.4 Package		MI2.4 Scrap packaging	MI2.4 Scrap packaging	MI2.4 Scrap packaging

		expense	expense	expense
M2.5 Stage Product				
M2.6 Release Finished Product to Deliver				

Table 5. Portion of RBM for the Deliver process

Deliver RBM	**RBS**	
	External	
	Catastrophic	
ABS	EXD.1 Nature disasters	EXD.2 Man-made accidents
D2:Deliver Make-to-Order Product		
D2.5 Build Loads		
D2.6 Route Shipments		
D2.7 Select Carriers and Rate Shipments		
D2.11 Load Product and Generate Shipping Docs		
D2.12 Ship Product	DI2.12 Delivery performance to customer commit date	DI2.12 Delivery performance to customer commit date
D2.13 Receive and Verify Product by Customer	DI2.13 Perfect order fulfilment	DI2.13 Perfect order fulfilment
D2.15 Invoice		

Table A.1. ABS for the Source Process

Level 0	**Level 1**	**Level 2**
Source Process	P2 Plan Source	P2.1 Identify, Prioritize, and Aggregate Product Requirements
		P2.2 Identify, Asses, and Aggregate Product Resources
		P2.3 Balance Product Resources with Product Requirements
		P2.4 Establish Sourcing Plans
	S2 Source Make-to-Order Product	S2.2 Receive Product
		S2.3 Verify Product
		S2.4 Transfer Product
	ES Enable Source	ES.2 Assess Supplier Performance
		ES.3 Maintain Source Data
		ES.4 Manage Product Inventory
		ES.5 Manage Capital Assets
		ES.6 Manage Incoming Product
		ES.7 Manage Supplier Network
		ES.8 Manage Import/Export Requirements
		ES.10 Manage Supplier Agreements

Table A.2. RBS for the Source Process

Level 0	Level 1	Level 2	Level 3	Literature Source
Source process	External	Catastrophic	EXS.1 Nature disasters	See Table 1
			EXS.2 Man-made accidents	
		Economic	EXS.3 Fuel price fluctuation	
			EXS.4 Exchange rate fluctuation	
			EXS.5 Changes in the economic situation	
		Social	EXS.6 Labour strikes	
			EXS.7 Changes in the network of transportation hubs	
			EXS.8 IT system functioning	
		Legal	EXS.9 Changes in import/export regulations	
			EXS.10 Tariff changes	
		Industrial	EXS.11 Market price of resources changes	
			EXS.12 Production technological changes	
			EXS.13 Product design changes	
		Partner	EXS.14 Supplier business	Chopra and Sodhi 2004
			EXS.15 Supplier product quality	Zsidisin et al. 2000
			EXS.16 Supplier capacity	Lee et al. 1997

			constraints	
			EXS.17 Supplier behaviour	John 1984
			EXS.18 Supplier production continuity	Wagner and Bode 2006
	Internal	Strategic	IS.1 Attitude about information sharing	Yigitbasioglu 2004
			IS.2 Investment on information system	
		Tactical	IS.3 Supplier assessment criteria	Chopra and Meindl 2004
			IS.4 Inventory policy	
		Operational	IS.5 Machine performance during transiting of the sourced products	
			IS.6 Operator's operations during transiting of the sourced products	

Table A.3. RBS for the Make process

Level 0	**Level 1**	**Level 2**	**Level 3**	**Literature Source**
Make process	External	Catastrophic	EXM.1 Nature disasters	See Table 1
			EXM.2 Man-made accidents	
		Social	EXM.3 Labour strikes	
			EXM.4 IT system functioning	
		Legal	EXM.5 Tariff changes	
	Internal	Strategic	IM.1 Capacity management	Spekman and Davis 2004
			IM.2 Information system	
			IM.3 Attitude about information sharing	
		Tactical	IM.4 Inventory replenishment model	Martha 2002
			IM.5 Internal transportation path decisions	
		Operational	IM.6 Production scheduling	Chakraborty et al. 2009
			IM.7 Machine performance	
			IM.8 Operator's operations	
			IM.9 Production process	

Table A.4. RBS for the Deliver process

Level 0	Level 1	Level 2	Level 3	Literature Source
Deliver process	External	Catastrophic	EXD.1 Nature disasters	See Table 1
			EXD.2 Man-made accidents	
		Economic	EXD.3 Fuel price fluctuation	
			EXD.4 Exchange rate fluctuation	
			EXD.5 Changes in the economic situation	
		Social	EXD.6 Labour strikes	
			EXD.7 Changes in the network of transportation hubs	
			EXD.8 IT system functioning	
		Legal	EXD.9 Changes in import/export regulations	
			EXD.10 Tariff changes	
		Partner	EXD.11 Financial health of the customers	
			EXD.12 Behaviour of the intermediaries	
	Internal	Strategic	ID.1 Warehouse network design	Chopra and Meindl 2004; Chopra and Sodhi 2004
			ID.2 Information technology infrastructure	
			ID.3 Attitude about information sharing	
		Tactical	ID.4 Inventory decisions	
			ID.5 Transportation strategy	
		Operational	ID.6 Planning of shipment	

			transfers between different modes	
			ID.7 Operator’s operations while handling finished goods	
			ID.8 Machine performance during transiting of the finished goods	