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Supply chain risk in turbulent environments—A conceptual model for managing supply chain network risk

Peter Trkman [a,*], Kevin McCormack [b]

[a] University of Ljubljana, Faculty of Economics, Kardeljeva ploscad 17, 1000 Ljubljana, Slovenia
[b] DRK Research, Raleigh, NC, USA

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ABSTRACT

Supply risk or the likelihood of supply disruptions is emerging as a key challenge to supply chain management. The ability to identify which supplier has greater potential of a disruption is a critical first step in managing the frequency and impact of these disruptions that often significantly impact on the supply chain. This paper presents preliminary research concepts regarding a new approach to the identification and prediction of supply risk. This approach to the assessment and classification of suppliers is based on supplier's attributes, performances and supply chain characteristics, while it is also modified by factors in the supplier's specific environment. The challenges posed to supply chains due to a turbulent environment (both from within the industry and external influences) are examined. A new method for the assessment and classification of suppliers based on their characteristics, performances and the environment of the industry in which they operate is presented. The findings are explained within the contingency theory.

1. Introduction

The risk of disruptions caused by both factors within supply chains (SCs) and outside environmental forces is one of the main concerns of both practitioners and researchers. Supply chain risk management (SCRM) is therefore a field of escalating importance and is aimed at developing approaches to the identification, assessment, analysis and treatment of areas of vulnerability and risk in SCs (Neiger et al., 2009). Various trends that enhance exposure to risks, such as the increased use of outsourcing, globalisation, reduction of the supplier base; reduced buffers, increased demand for on-time deliveries or shorter product life cycles (Norrman and Jansson, 2004) are ratcheting up the importance of SCRM. This is highlighted by several practical examples of the high cost of improper preparation for and response to various events (Chopra and Sodhi, 2004).

Currently, SCRM approaches seek to measure either supplier attributes or the SC structure, use the findings to compare suppliers and predict disruption. The results are then used to prepare proper mitigation and response strategies associated with these suppliers. SCRM is most often a formal process that involves identifying potential losses, understanding the likelihood of potential losses, and assigning significance to these losses (Giunipero and Eltantawy, 2004). A typical example of such an approach is the PRAM methodology developed by the Dow Chemical Company to measure SC risk and its impacts. This approach examines the following factors of a SC: supply market risk, supplier risk, organisation risk and supply strategy risk (Hackett Group, 2007).

Due to the relative newness of the SCRM field it is currently chaotic and somewhat disorganised. There are several different classifications of risks and methodologies and too often they focus only on the prediction of disruptive events instead of the root causes of

* Corresponding author. Tel.: +386 1 5892 400; fax: +386 1 5892 698.
E-mail addresses: peter.trkman@ef.uni-lj.si (P. Trkman), kmccormack@drkresearch.org (K. McCormack).

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uncertainties. Frequently, only disruptive events (such as bankruptcy, natural disaster or the possibility of a terrorist attack) are included, whereas continuous changes due to a turbulent environment (e.g. a change in customer tastes, technology shifts or supplier priorities) are ignored.

While important, such approaches also usually neglect the fact that the market, technology and environmental turbulence in the supplier's particular market segment are significant factors influencing the relationship between supplier attributes, performance in a SC and the potential for disruptions. Since various suppliers (and suppliers' suppliers) operate in different markets and environments, their turbulence varies and therefore the forces influencing a supplier also differ. While a certain supplier strategy (e.g. ordering large batches to decrease procurement costs or single-source suppliers with long contractual commitments) may be acceptable in a non-turbulent environment, it may be detrimental in a more turbulent one (e.g. in the presence of quick technological advances such as microprocessors or large commodity price swings). Considering all of this, the same supplier attributes, strategy and structure may pose considerably different risks of disruption. Therefore, a comprehensive approach to SCRM has to include supplier-associated turbulence as well as various sources of uncertainty due to supplier attributes such as strategy, structure and performance.

This paper suggests a framework for the assessment of supplier risk of disruption based on their strategy, structure, performance and attributes as modified by turbulence in their specific environment. The approach is grounded within the contingency theory. Since there is no single best way of organising SCs to manage uncertainties and risks, firm-to-firm risk comparisons are therefore the result of environmental demands and attributes that tend to be firm-specific.

The structure of this paper is as follows. First, the role and challenges of SCM in a turbulent environment are presented. Then the main sources of uncertainty and risks are identified and classified. The role of endogenous (market, technology) and exogenous uncertainty in SCRM is analysed. Several approaches to supplier selection, performance measurement and management are discussed. The role of SC strategy and structure is emphasised. Then, a conceptual model for measuring supplier performance is proposed along with an approach to supplier classification and portfolio management. Finally, the application of the framework is shown with the case study from automotive industry.

2. Theoretical background

The claim is often heard that in today's world competition is no longer between individual companies but between SCs (Trkman et al., 2007; Li et al., 2005). Therefore, in order to understand a firm's position a larger network has to be studied and not just a dyadic relationship with a supplier (Wathne and Heide, 2004) since the quality, cost and risks of a product or service offered in the market is a function not only of the particular firm's capabilities but also the supplier network that provides inputs to the enterprise (Modi and Mabert, 2007). In theory, SCM means a proactive relationship and integration among various tiers in the chain (Trkman et al., 2007). Yet, in practice, increased dependency between companies also means they become more exposed to the risks facing other companies (Hallikas et al., 2004). Consequently, SCs are fragile, in particular due to environmental disruptions beyond their control (Zsidisin et al., 2005). A typical example is the bankruptcy of the Chrysler supplier Plastech, driven by liquidity and cash-flow problems, which led to the temporary shutting down of four Chrysler plants in 2008 that resulted in Chrysler losing millions of dollars.

Effective management of a SC is therefore no easy task since market leaders must face and cope with a multitude of different turbulence factors as well as each supplier's individual issues and relationships (Chakravarthy, 1997). This makes it very difficult to create an effective disruption management strategy, which is a necessary component of a firm's overall SC strategy (Tomlin, 2006). Consequently, effective SCM is rarely fully realised in practice (Li et al., 2005). This leads some to claim that environmental uncertainty can cast doubts on the effectiveness of SCM as a tool to improve a firm's operational performance and profits (Hsu, 2005). It could also be claimed that environmental uncertainty increases the importance of SCM—while many suppliers can perform well in a stable environment fewer can perform well in a more turbulent one. A supplier in a non-turbulent market can operate with a flawed strategy or structure and still achieve an average performance while such a supplier in a turbulent environment could pose a significant risk to the whole chain.

To add to the complexity involved, each focal firm has different sorts of turbulence in its environment that are driven by factors such as industry forces, branches, locations, downstream SC factors like distributors and customers, etc. Accordingly, the same management approach and performance rankings cannot be used to manage the same supplier that may service different company locations or divisions. In addition, the importance of suppliers in a particular SC varies. Some are more important for the overall success of the chain than others. It is likely that risk in relationships with strategic suppliers is more important for SC performance (Hunter et al., 2004).

Our research contributions in this paper can be explained within the framework of the contingency theory. This claims that there is no single best way of organising/leading and an organisational/leadership style that is effective in all situations (Fiedler, 1964) and there is no universal set of choices that is optimal for all businesses (Gingsberg and Venkatraman, 1985). Therefore, firm-to-firm strategy differences are the result of environmental demands and tend to be firm-specific. This lack of generalisability precludes organisations from utilising a universal strategy (Fredericks, 2005). A firm's business performance is affected by how well its organisational resources match with the corresponding business environment (Kim and Pae, 2007). However, in today's

world the environment is ever changing and interconnected and unknown exposures of other partners in the network to risk factors from a single company are growing. Therefore, before selecting a SC strategy it is first necessary to understand the sources of uncertainty and individualise the best way of reducing this level of uncertainty (Cucchiella and Gastaldi, 2006). A sustainable competitive advantage lies in a firm's or chain's ability to quickly sense and adapt to the changing environment it faces (Calantone et al., 2003). This now includes each individual supplier's environments as well as that of the focal firm.

2.1. Risk and turbulent environments

Claims that we live in an uncertain and ever-changing world already form part of almost every paper in business research or practice. The dynamics of a competitive environment (technological turbulence, competitive intensity and customer type) have long been identified as an important contingency variable in conceptual and empirical studies in operations management (Fynes et al., 2005). It is clear that a significant degree of uncertainty and thus risk surrounds many SC situations.

Most definitions of risk have the following in common: likelihood of the occurrence of a particular event or outcome; consequences of the particular event or outcome occurring and the causal pathway leading to the event (Ritchie and Brindley, 2007). SCRM can be defined as the management of SC risks through co-ordination or collaboration among the SC partners so as to ensure profitability and continuity (Tang, 2006). The incorporation of risk constructs and management responses within SCM reflects both theoretical imperatives and practitioner requirements (Ritchie and Brindley, 2007). Most research on risk proposes the following (or similar) steps for the reduction of risks: risk identification; risk analysis; risk reducing/managing, and risk monitoring.

Since SCRM is a very broad topic several authors have attempted to classify risks based on various aspects. Some state that academic interests appear to focus mostly on the risks associated with logistics and their impact on the timely delivery of goods (Spekman and Davis, 2004). Yet these are only a subset of all the risks posed by the environment or other companies in the chain.

Risks may be divided into operational and disruption risks (Tang, 2006). A complementary division distinguishes between strategic, tactical and operational risks (Ritchie and Brindley, 2007). Zeng et al. (2005) divides risks based on their origin from capacity limitation, technology incompatibility, supply disruptions, currency fluctuations or disasters.

Hunter et al. (2004) classified risks based on their probability and importance, which is very similar to the classification based on probability and impact in Hallikas et al. (2004). Even subsets of risks were further classified—i.e. risks from the environment can be classified in terms of uncertainty from customers/demand, suppliers, and technology (Li and Lin, 2006; Chen and Paulraj, 2004).

The approach offered in this paper is novel in that it does not deal with an ex post identification or assessment of risk but rather with the ex ante configuration of a SC and the selection of suppliers in such a way that risk is properly managed. Also, risks that potentially influence the chain's ongoing performance in terms of effectiveness and/or efficiency are addressed and not just those that might result in a crisis or the failure of an enterprise (Ritchie and Brindley, 2007). In our approach, the main dimension of risks and sources of turbulence are considered (Hackett Group, 2007), although their classification differs slightly.

Earlier research often neglects an important division of risks, namely the origin of risks which can either be within a chain or from the outside environment. In order to distinguish between the different kinds of risks, the sources of uncertainty need to be separated into two different constructs:

- *Endogenous uncertainty*: The source of uncertainty/risk is inside the SC and can lead to changing relationships between focal firm and suppliers, the most notable kinds are market and technology turbulence.
- *Exogenous uncertainty*: The source of uncertainty/risk is from outside the SC. We suggest further dividing these risks into the two most notable kinds; namely discrete events (e.g. terrorist attacks, contagious diseases, workers' strikes) and continuous risks (e.g. inflation rate, consumer price index changes).

This division is important because of the difference taken in the risk mitigation approach. Endogenous uncertainty can be reduced with a proper and proactive relationship with a supplier (using methods like information sharing, relationship development, joint reviews, etc.) (Ritchie and Brindley, 2007). Exogenous uncertainty cannot be generally reduced; however, a proper structure of the chain can enable resiliency and a quicker or even partly a proactive response.

This classification of risks primarily follows the proposal in Ritchie and Brindley (2000) that categorised the primary sources of risk as exogenous (e.g. technology developments, changing consumer tastes) and endogenous (e.g. the quality of internal financial control systems, effective management structures). It should be noted that our model includes technological turbulence as an endogenous characteristic of a whole SC, while it might be considered as exogenous at a single company level. In certain cases it is also possible to consider technological turbulence as exogenous (e.g. a breakthrough scientific invention).

On the other hand, the proposal extends the division of risk into risks arising from co-ordinating supply and demand, and risks arising from disruptions Kleindorfer and Saad (2005) and the division of risks into internal and external as in Blackhurst and Chidambaram (2006). A similar division into internal and external uncertainty was made in Cucchiella and Gastaldi (2006) but the studied system was a single company and not a whole SC. The various kinds of uncertainty and their impacts on SCs are discussed below.

2.2. Endogenous uncertainty

Turbulent conditions are characterised by frequent and unpredictable market and/or technological changes within an industry which accentuate risk and create an inability to forecast accurately (Calantone et al., 2003). In many markets it is becoming impossible to remove or ignore sources of turbulence and volatility. Hence, managers of SCs face the situation where they have to accept uncertainty and cope with it (White et al., 2005). Therefore, proper strategies are needed for dealing with uncertainty in the SC context.

An important question for SCM theory and practice is the influence of endogenous uncertainty on co-operation and integration with suppliers. The latter is often quoted as one of the most frequently used strategies in SCM—e.g. Lyons et al. (2004). While Stonebraker and Liao (2004) claimed that turbulence is positively related to SC integration, they offered no proof to support the claim. In line with the contingency theory, the correct answer may depend on the chosen strategy of the focal firm, the structure of its SC (customers, suppliers, and sources of uncertainties) and other factors. The claim has been substantiated by Koo et al. (2007) for market turbulence and by White et al. (2005) for technology turbulence. Both found that integration is beneficial in some cases and detrimental in others.

While most previous research studied either turbulence at the SC level or turbulence for a focal firm in a chain, this paper suggests that the turbulence experienced by suppliers and their strategies for dealing with the turbulence should also be considered. A focal firm in a large (e.g. automotive, high-tech, etc.) SC usually has suppliers from different industry/services branches. Each supplier is operating in different turbulent environments and therefore its optimal strategy and potential problems impacting on the whole SC can vary considerably. This was often neglected in previous research efforts.

It should be noted that everyday operational risks such as late deliveries, risks of sharing production information with vendors (Rahman, 2004), the risk of opportunistic behaviour of the supplier (Spekman and Davis, 2004) and similar uncertainties are not part of turbulence as defined in this paper. These factors are measured in other parts of the risk model, specifically the supplier performance evaluation, and can be a consequence of supplier, organisation, supply strategy or supply market risk (Hackett Group, 2007).

2.2.1. Market turbulence

Market turbulence is likely to arise from the heterogeneity and rapid changes in the composition of customers in the market and their preferences (Kandemir et al., 2006). It is characterised by continuous changes in customers' preferences/demands, in price/cost structures, and in the composition of competitors (Calantone et al., 2003). In a turbulent market, the market shares of a SC (or its business units/divisions) and its competitors can change relatively quickly and it is difficult to forecast demand and customer tastes. Customers tend to look for new products constantly and new customers often have product-related needs that differ from existing customers. A firm in a more turbulent market has to modify its products and approaches to the market more frequently (Kandemir et al., 2006). Market turbulence can also be caused by mergers or acquisitions. If a supplier is acquired by another company or the divestiture of a certain division occurs, this can result in delivery or quality problems.

There are different views on the impact of market turbulence on the relationship and behaviour of firms in a SC. On one hand, a fast changing market might incline firms to co-ordinate their efforts to reduce uncertainty and respond to changes in demand. On the other hand, a firm operating on its own might be able to respond more quickly to the changes in customer preferences while the process of communication and joint-decision-making between alliance partners might introduce delays and limit proactive measures (Chatterjee, 2004).

The answer might lie in the fact that (in line with the contingency theory) both views might be correct. A focal firm with a flawed strategy and structure of its SC can survive in a less-turbulent environment since most of the potential risks have a low likelihood. On the other hand, in a turbulent market a focal firm should have a very clear strategy for dealing with turbulence, although the chosen strategies for different suppliers and chains can be very different. This claim was substantiated by Koo et al. (2007) who found that market turbulence positively influences the level of adoption of different generic strategies (cost leadership, market differentiation, innovative differentiation, focus), while it does not have a direct impact on firm performance. Obviously there are more or less successful chains in both more and less turbulent environments.

In line with earlier authors (Calantone et al., 2003; Wong and Ellis 2007; Kandemir et al., 2006; Koo et al., 2007), the following measures are proposed for market turbulence (a scale from 1 to 5, strongly disagree to strongly agree):

1. We cater too many of the same customers as in the past (reverse scoring).
2. In general, in this business unit (or division) the market share is stable among the same competitors (reverse scoring).
3. Demand and customer tastes are fairly easy to forecast (reverse scoring).
4. Our customers tend to look for new products all the time.
5. New customers tend to have product-related needs that differ from our existing customers.

2.2.2. Technological turbulence

Technological turbulence refers to the degree to which technology changes over time within an industry and the effects of those changes on the industry (Chatterjee, 2004). Technological turbulence arises from changes in the underlying technologies of products or services and their rates of obsolescence (Kandemir et al., 2006). Technical dynamics include how fast the related technology is changing, as well as breakthroughs in the

manufacturing process, and mass production techniques (Hsu and Chen, 2004).

When technology is changing rapidly, the firm must be able to share information more quickly than when technology is more predictable. SCRM is therefore expected to play a more important role in such situations (Fynes et al., 2005). Alliances may be more effective in highly technologically turbulent markets by making it possible to accelerate the time to market and gain access to complementary products or technologies without risks of internal development (Chatterjee, 2004). Interestingly, a technology orientation enhances a firm's performance in highly turbulent markets while it is detrimental in less turbulent markets (White et al., 2005).

However, the finding that greater technology turbulence does not make strengthen the relationship between SC relationship quality and SC performance (Fynes et al., 2005) seems not to support these claims. Similarly, Zhou et al. (2005) claims that firms can take advantage of technological advances to significantly alter the components of an existing SC.

The answer to the question about whether to integrate with suppliers or to instead enable a more flexible change of a SC component might therefore be quite simple. A focal firm should integrate more with those suppliers that are able to cope with technological turbulence and provide critical components of products/services. It should not lock itself in with suppliers that are unable to do so and (if needed) change those suppliers in order to obtain the technological developments required to retain the chain's competitive advantage and reduce the risks. Once again, it should be emphasised that not only the different units of a focal firm but also different suppliers operate in markets with different technological turbulence and therefore different strategies should be employed.

Based on these observations and the empirical findings of earlier authors (Calantone et al., 2003; Wong and Ellis, 2007; Auh and Menguc, 2005; Kandemir et al., 2006; Koo et al., 2007; Zhao and Cavusgil, 2006), we propose the following measures for technological turbulence of the market of each individual supplier (a scale from 1 to 5, strongly disagree to strongly agree):

1. The technology in our industry is changing rapidly.
2. Technological changes provide big opportunities in our industry.
3. It is very difficult to forecast where the technology in our industry will be in the next 2–3 years.
4. A large number of new product ideas have been made possible by technological breakthroughs in our industry.
5. In our principal industry the modes of production and service often change.
6. The rate of product/service obsolescence in our industry is very high.

2.3. Exogenous uncertainty

In addition to changes in market and technology, a SC also have to deal with disruptions from its environment either in the form of natural disasters (e.g. hurricanes, floods, earthquakes) or human-centred issues (e.g. a labour strike, fraud, a malfunction in production, delays in logistics, terrorist attacks). Possible disruptions can be classified as long-term uncertainties (e.g. raw material/final product unit price fluctuations, seasonal demand variations) and short-term uncertainties (cancelled/rushed orders, equipment failure, etc.) (Gupta and Maranas, 2003), while those risks can be classified based on their likelihood and impact on business (Hackett Group, 2007).

Generally, organisations plan to protect themselves against recurrent, low-impact risks in their SCs but ignore high-impact, low-likelihood risks (Chopra and Sodhi, 2004; Faisal et al., 2006). Even though organisations are often unable to manage the source of the risk exposure, it is vital to identify the sources of potential problems and possible consequences. In this way a proper response that might range from avoidance, transfer, mitigation to monitoring or even acceptance of risk (Khemani, 2007) can be taken.

Our proposed classification of exogenous uncertainty is novel by virtue of its distribution of risk on the probability distribution of its impact:

- *Continuous risk*: Events where the costs of potential changes are continuous in nature and relatively easy to predict (a typical example is changes in raw material prices). For such risks, a calculation of the effect of a certain price increase on profit margins can be made and different insurance instruments (e.g. future and forward contracts that can mitigate price volatility (Aggarwal and Ganeshan, 2007)) can be arranged in advance.
- *Discrete events*: This category consists of low-likelihood, high-impact events which can be classified as terrorism, the spread of diseases, natural disasters (Faisal et al., 2006). Political events such as those occurring in Venezuela or Myanmar can also pose a disruption risk. Transport disruptions between various links in the chain can also cause considerable delays or non-deliveries (Wilson, 2007). These are often hard to predict and their consequences can be large yet hard to measure. Nevertheless, the likelihood of such events can often be estimated (e.g. it is relatively likely that there will be hurricanes in the Gulf of Mexico in summer or heavy snowstorms in the Alps in winter) and should therefore be included in the risk ratings. Therefore, the questionnaire for exogenous uncertainty includes the likelihood of such events which then add up to a higher score for the turbulence of the suppliers' environment.

Such a division is important due to the different possible strategies for risk prevention and response. Continuous risk can be 'managed' in a way whereby a focal company searches for an optimum between the probability of such events and the costs of their impact and prevention. A typical example is the probability of a change in exchange rates and its consequences that can be modelled in a

framework that can be used for planning within global SCs (Kazaz et al., 2007). However, it can be hard to predict exactly or estimate the impact of the occurrence of discrete events. Still it is possible to apply one of the strategies discussed in Khemani (2007): avoid, transfer, mitigate, minimise, respond, monitor or accept to manage those risks.

While endogenous uncertainty can be measured with precise (and previously validated) questionnaires, the exogenous uncertainty is harder to estimate. Therefore, our proposed questionnaire builds on the main sources of exogenous uncertainty identified in Handfield and McCormack (2007), Juettner (2005), Kleindorfer and Saad (2005) and Norrman and Jansson (2004). A scale from 1 to 5, strongly disagree to strongly agree, is suggested.

Additionally one "open" type question was added, namely the chance and potential impact of other discrete exogenous events (scale 1–10). Its intention is to allow the analyst to include other supplier-specific exogenous risks into the evaluation.

Continuous risk:

1. Interest rates greatly affect our industry.
2. Changes in the CPI (consumer price index) greatly affect our industry.
3. Changes in GDP (gross domestic product) greatly affect our industry.
4. Changes in commodity prices greatly affect our industry.

Discrete risks:

1. The potential of a major SC disruption due to regulatory issues is high.
2. The potential of a major SC disruption due to man-made disasters (e.g. terrorism and political instability) is high.
3. The potential of a major SC disruption due to a natural hazard (e.g. earthquakes, storms, floods, fires, diseases) is high.
4. The potential of a major SC disruption due to a transportation disruption (accident, transportation union strike, etc.) is high.
5. The potential of a major SC disruption due to other discrete events is high (scale 1–10).

3. Prediction of supplier risk of non-performance in a SC

Previous sections have highlighted the main challenges to SCs due to turbulence and raised the question of the proper identification of suppliers that have a greater potential of a disruption. The question also have a considerable practical application; e.g. AMR research found that the adoption of and spending on SCRM is quickly increasing and supplier failure and supply continuity is the number one risk factor (Hillman and Keltz, 2007).

It is clear that it is necessary to measure supplier performance in order to manage and predict disruption. However, the classic supplier performance measurement index such as that presented in e.g. Cormican and Cunningham (2007) which includes on-time delivery, quality and total costs seem to be too narrow. Others, e.g. Huang and Keskar (2007) provide a more comprehensive classification of measures of performance into product (reliability, responsiveness, flexibility), supplier (costs, assets) and society-related (safety, environmental) categories. The SCOR model (e.g. Lockamy and McCormack, 2004) provides SC performance measures based on the five decision areas in a SC (plan, source, make, deliver, return).

To summarise the classic supplier performance measures can be distributed into strategic (lead time against industry norm, quality, cost saving, pricing), tactical (order cycle time, cash flow, quality assurance methodology and capacity flexibility) and operational level measures (adherence to the developed schedule, number of complaints, defect-free deliveries) (Gunasekaran et al., 2004).

These are similar performance measures might be directly suitable for suppliers of commodities where the main indicators are usually price, quality (if applicable), lead times and delivery performance (Stadtler, 2005). However, they cannot fully predict the risk of supplier failure or non-performance since two suppliers with a similar current performance may pose considerably different risks. Yet those supplier performance ratings are very useful for the measurement of one construct in the proposed model (namely supplier performance).

The selection and evaluation of suppliers of most materials is increasingly seen as a strategic issue for companies whereby decisions must not be solely based on the abovementioned selection criteria (Araz and Ozkarahan, 2007). Closer co-operation and dependence on a single source or strategic supplier demands more advanced measures (e.g. responsiveness to changes, proactive development) and the ex ante prediction of the likelihood of supplier performance glitches. The process of evaluating potential suppliers must include the risk of disruption to the operation (Levary, 2007). In order to find those partners which best fit in with the existing SC, an analysis of potential partners along several dimensions is needed. Therefore, effective methodologies that have the capability to evaluate and continually monitor suppliers' performance are needed (Araz and Ozkarahan, 2007).

The main contribution of our proposed approach (shown in Fig. 1) is that it is based on SC characteristics, its structure and a supplier's attributes and performance, modified by factors in the supplier's specific environment, namely exogenous and endogenous uncertainty. The proposition of the model is that the market, technology and environmental turbulence of each supplier is a significant factor modifying the relationship between supplier characteristics, SC attributes, strategy and structure and supplier risk of non-performance or disruption in a chain. In this way the proposed model extends the previous classifications of SC risk from SC entities (such as supplier, manufacturer, distributor, etc.) (Zhang and Huang, 2006).

While uncertainty was thoroughly discussed above, a short discussion of the importance of supplier characteristics and SC structure and strategy is given in this section.

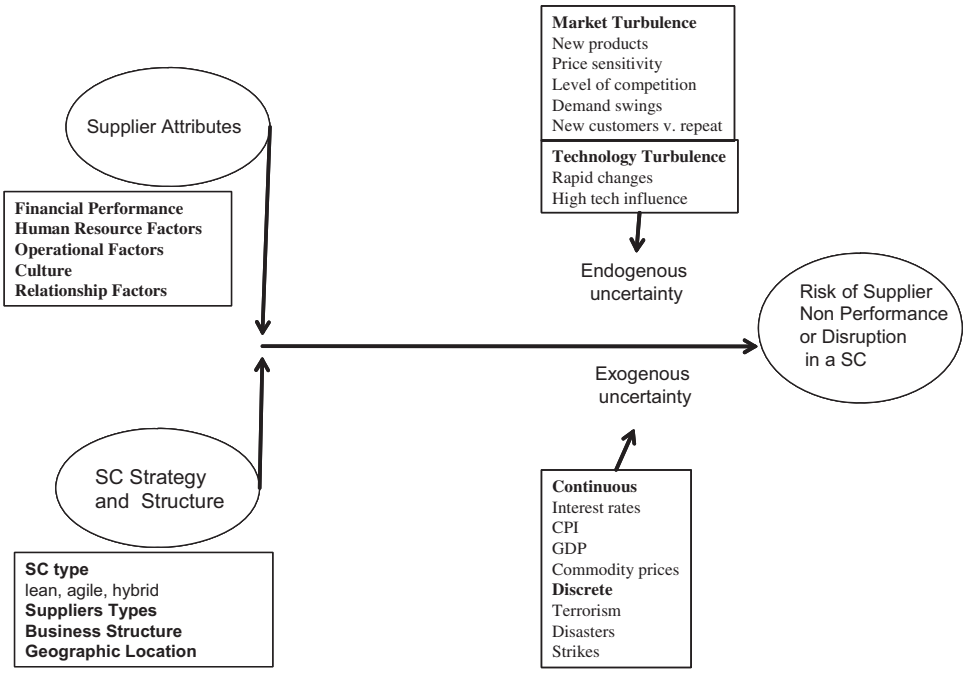

Fig. 1. Conceptual model.

The selection of supplier characteristics mainly follows the PRAM methodology (Hackett Group, 2007) which identifies characteristics such as supplier financial and operational performance, material quality, human resource quality, compliance with the work process and IT system stability as the main supplier characteristics that affect the likelihood of a supplier-connected disruption or a decrease in the standard of its performance. A supplier with a good record in these categories is less likely to underperform in the chain.

However, it should be emphasised that the performance of a company as a whole and the performance of a company in a chain/alliance may not be the same (Kandemir et al., 2006). Several studies that mainly deal with the assessment of supplier qualification are limited because they only provide evidence of a supplier's particular skills or abilities (Wathne and Heide, 2004) but do not guarantee that the supplier will actually apply the skills to the relationship in question (Kirmani and Rao, 2000).

The other question, emphasised by the contingency theory approach, is whether supplier characteristics will fit with the SC structure and strategy. In the model only a few of the most important characteristics of the SC structure and strategy are currently included.

The first is the type of SC involved: e.g. it can be lean, agile and hybrid (Vonderembse et al., 2006). For an agile SC the flexibility of the supplier and its responsiveness to market turbulence is vital; for a lean SC reliability and low variations in lead-times/performance are of utmost importance. Most practical situations require a combination of both characteristics in hybrid SCs.

Second, the importance of procured materials for the focal company is vital. Different approaches to strategic, bottleneck, leverage and non-critical items may be needed (Kraljic, 1983). Our proposed model is most suitable for strategic items where, the use of proper analytic techniques is crucial (Kraljic, 1983; Vonderembse et al., 2006). Equally important is the risk estimation of bottleneck items where price is not so important, but potential performance glitches due to a failure of the supplier to perform in a turbulent environment may be equally detrimental. For leverage and non-critical items the abovementioned traditional indicators may be enough for the monitoring of suppliers' performance, although in certain cases (e.g. a very large supplier of those items) an additional analysis with the proposed model may be beneficial.

Next is the geographical dispersion of the SC, namely the geographical scope of the locations of the suppliers, production facilities, distributors, and customers in the SC (Stock et al., 2000). Large distances increase the possibility of a transport disruption and can reduce flexibility in the case of great market turbulence. In addition, a fit between enterprise logistics, integration capabilities and its SC structure is needed (Stock et al., 2000).

Finally, the business structure, specially the degree of single sourcing importantly influences the risks facing a SC (Wagner and Bode, 2006). Special attention should be paid to those suppliers that are a single source of important materials or components. A relatively unreliable single-sourcing supplier poses a considerably greater risk than in the event of multiple-sourcing. A typical practical example is a fire in one of the Philips plants that caused serious damage to Ericsson, while the disruption to Nokia SC was minimal (Chopra and Sodhi, 2004).

In such a way the proposed model provides a comprehensive tool for estimating the possibility of

supplier-connected risk, while taking both the turbulence of the supplier market, technology and environment and the characteristics of a supplier, its role within the SC structure and strategy into account.

Obviously, the mentioned constructs are not enough to fully manage the possible risk of supplier non-performance. The results arising from the model should be used in combination with one of the several methodologies for risk mitigation such as the PRAM that measures the risks of supply disruptions and their impact on SC profitability. The detailed methodology for estimating the value and risk of SCM improvement projects presented in Brun et al. (2006); while e.g. Khemani (2007) analyses potential approaches to identified risks.

3.1. Supplier portfolio management

As shown in the previous section, new approaches are needed to manage risk in both the dyadic relationship with suppliers and on the SC level. The supplier performance, risk and its environment should be measured and (in line with the contingency theory) different strategies for different suppliers should be employed. It is vital to transform this information into correct decisions within the chain. Therefore, many researchers have made efforts to develop supplier selection methodologies (Huang and Keskar, 2007).

To further explore the possibilities of using a supplier risk prediction measurement in order to select and manage suppliers the framework in Fig. 2 was developed. In the framework, each supplier position is determined by two factors: the supplier's performance in the chain and the turbulence of the environment it operates in. The division is in line with the finding that, in order to secure a satisfactory performance from suppliers, the focal company should rely on different control mechanisms depending on the level of environmental uncertainty (Ryu and Eyuboglu, 2007).

The size of the circle indicates the strategic importance of a supplier to the chain (e.g. A is a very important 'rock'; B is a mildly important 'bouncer'). The distribution of all suppliers in the framework enables an overview of potential risks and weak points facing the chain. Such an analysis can help a focal company to identify if its supplier mix is suitable and in line with its strategy.

The basic idea of SCRM should therefore be to have in place a proper combination of rocks (that add stability to the chain) and stars (that add a bit of creativity and the possibility to improve). This is in line with the claim that SCs should encourage a degree of environmental uncertainty in order to gain a competitive advantage from their flexible capabilities (Stevenson and Spring, 2007). Those two types are the main "treasures" of a chain and should be properly managed and rewarded.

Bouncers are the most "difficult" group. The chain leader should investigate whether to invest in them (with different supplier development programmes, information sharing, joint investments, etc. in order to facilitate their move into the star group—see e.g. Li et al. (2007) for an analysis of the effects of such programmes) or to seek

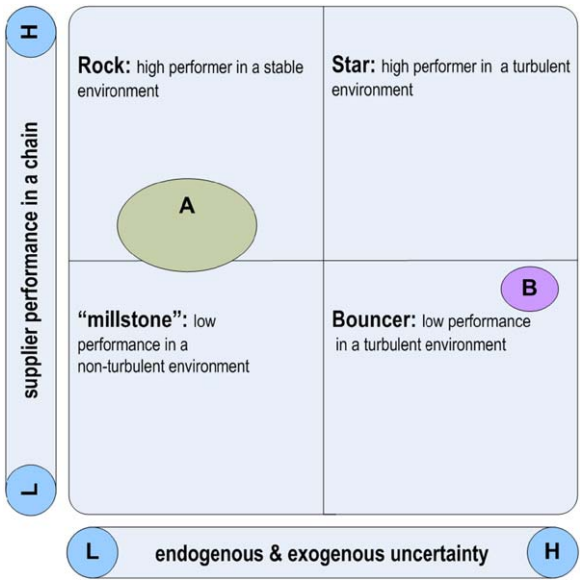

Fig. 2. Supplier performance and uncertainty matrix.

alternative solutions (which is not necessarily easy due to the turbulent environment). Millstones are the "weakest" link. Although the possibility to improve their performance through a supplier development programme should be investigated, their replacement may be a more desirable option.

The most desirable combination of suppliers depends (in line with contingency theory) on the operating environment of the SC leader, its strategy and the type of the SC involved. For innovative firms the proper combination would include several stars or even bouncers, while for cost leaders a larger proportion of rocks are probably more suitable.

Dual/multiple sourcing strategies may be a preferable choice, especially where the main supplier is a bouncer. A backup supplier may be a star; even another bouncer can help lower the risks. If a supplier is a millstone, then replacing such a supplier may be more appropriate. Therefore, a combination of a bouncer (who may have a lower level of reliability but is preferred due to e.g. lower price) and a star (more reliable but with a higher price) could be a good combination. Obviously, the final answer is contingent on the focal firm's strategy and whether the focus is on reliability, high quality or low costs. The final selection then also depends on a trade-off analysis of the expected costs and risks (Wu and Olson, 2008).

4. Case: supply risk and turbulence in an automotive SC

How the developed theoretical framework is used is illustrated with a case study in the automotive industry. This industry was chosen since the measurement of supplier performance has often been illustrated by research within the automotive industry (see e.g. Buxmann et al., 2004; Demeter et al., 2006; Doran, 2004;

Kotabe et al., 2003; Prahinski and Benton, 2004; Schmitz and Platts, 2003; Singh et al., 2005). There are several reasons for that: the relationships between suppliers and automobile manufacturers are well developed and fairly stable; suppliers represent a wide diversity of industries so the conclusions may be generalised across a variety of businesses; and the results fit within the established knowledge base (Prahinski and Benton, 2004). Further, the number of suppliers in the automotive industry is large, which adds to the importance of performance and risk evaluation (Schmitz and Platts, 2003).

Recently, automotive companies have been experiencing unplanned supplier events such as shortages, declining quality or in some cases even supplier bankruptcies on a frequent basis. The company in this case conducted a supplier risk assessment for selected commodity groups (castings, shocks, steering gears and aluminium wheels) in an attempt to mitigate the supplier-connected risks.

The objectives were two-fold: first, to assess all the criteria that contribute to supplier risks and, second, to implement mitigation steps with identified suppliers. A risk assessment approach was taken to measure supplier characteristics and performance. The assessment was conducted as a combination of interviews and online surveys that allow organisations to assess a large group of suppliers within a short timeframe. Online surveys measuring characteristics and the SC structure (location, transportation routes, etc.) were completed by selected supplier key informants. Risk analysts also rated the supplier's market and technology turbulence and its exogenous uncertainty.

These ratings were equally rated and then summed up to provide a turbulence index. Current supplier performance was also measured. The results are presented in a supplier portfolio matrix (Fig. 3) including suppliers' turbulence and current performance in the chain (the data are real but the company names have been changed). Critical suppliers with a high level of turbulence were identified based on this portfolio view. Their performance, environment and impact on the focal firm were then examined closely.

Two suppliers are chosen as an example: Fenton was in a low turbulent environment and consequently in the "rock" position in the supplier portfolio. Jupiter, on the other hand, had a similar performance rating but was in a highly turbulent environment. This placed it in the "bouncer" position. In addition, Jupiter was the single source of certain parts which considerably increased the impact of any potential disruption. Since the focus of this SC strategy is on a high level of reliability (as often found in the automotive industry—e.g. Demeter et al., 2006), the potential risk was too high for the focal company. Therefore, upon a closer examination and mainly influenced by the turbulence assessment mitigation plans were put in place and an investment was made in qualifying back-up suppliers for Jupiter.

Soon after this, Jupiter lost a large customer which greatly changed its financial position. This consequence of the market turbulence caused Jupiter's financial backers to withdraw, resulting in its collapse and liquidation. The back-up suppliers were notified and within one week the production was transferred to those suppliers. Without a consideration of turbulence, the mitigation of this risk may not have been a high priority and an expensive disruption would have been the outcome.

5. Conclusion

Judging from the growing number of papers in research journals and various stories in professional magazines, SCRM is a field of growing importance. The current approaches only offer a limited estimation of the risk of supplier non-performance. As is usual of a new field SCRM is currently disorganised and offers several different methodologies and various approaches to supplier-connected risks. The often neglected fact is that suppliers operate in different environments and those two suppliers with similar characteristics and performance can pose considerably different risks. Our approach enables the estimation of the risks and helps the company to make a more informed decision as to how much risk it is willing to take and which risks will it mitigate (either with dual/multiple sourcing or with the change of supplier).

Our paper has used the contingency theory to analyse the often conflicting earlier findings on the role of environmental turbulence in SCRM. It has conceptualised several ideas and constructs using the premise that market, technology and environmental turbulence in the supplier's market segment is a significant factor modifying the relationship between supplier characteristics, SC strategy/structure and the supplier risk of non-performance. It has provided a classification of uncertainties arising from a turbulent environment and offered a new way of looking at supplier-connected risks. A valuable synthesis and classification of earlier research and practitioners' efforts in the SCRM field was conducted. The application of the concepts and the framework were shown in a case study from automotive industry.

The paper has added an important insight into and extension of the contingency theory in two respects. First, both the environment of the supplier and the strategy of the focal company should be considered when estimating the likeliness of supplier non-performance. The same supplier characteristics can entail considerably different risks in different situations. Second, the supplier portfolio matrix introduces the notion that the role of a supplier as one of the suppliers in the chain should be included. The fit between the supplier portfolio and the SC strategy is crucial for successful operation of the chain.

Several important considerations for SC managers also arise from the findings. Our approach enables the ex ante prediction of possible supplier non-performance. Such suppliers should be closely monitored or (if possible) replaced. The approach also offers an important insight into the decision about investment in supplier development programmes or joint project/supplier integration. The focal company should not lock itself in with the suppliers that either cannot cope with the turbulence or do not fit within the SC strategy.

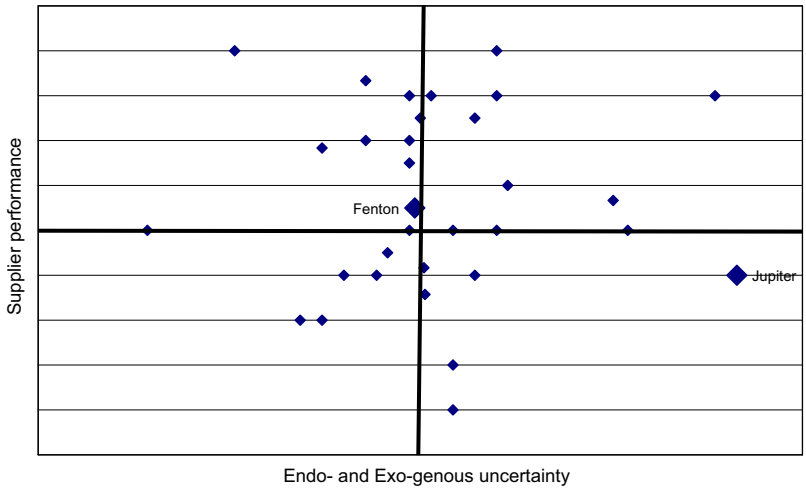

Fig. 3. Supplier performance and uncertainty matrix for suppliers in the case study.

The main future work is a detailed study of especially the SC strategy and structure construct. Currently, only the variables SC type, supplier type, geographical dispersion and business structure are included, with all being based on the literature review. A further conceptual extension of the construct along with statistical validation may be needed. Also, while the framework enables a coherent estimation of supplier-connected risks, it does not directly include the potential impact/loss due to a disruption or costs of mitigating a disruption (through e.g. a change of supplier or double sourcing).

A multiple case study involving an analysis of not only the suppliers of the focal firm but also the suppliers' suppliers would also be beneficial; several studies usually focus on a dyadic relationship instead of a sequence or even a network of several firms in the chain. The ability of the supplier to absorb the shocks and turbulence of its suppliers would be particularly interesting.

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