Developing a Supply Chain Risk Model

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Developing a Supply Chain Flow Risk Model

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ABSTRACT

A number of trends like globalisation, outsourcing, single sourcing, and leanness have together created a more vulnerable supply chain. This *increased vulnerability* has made supply chain risk issues a hot topic in academia as well as in industry. There has, however, been a lack of suitable models.

The objective of this paper is to develop *one* such model – a *conceptual model* with the help of which risks, seen from the perspective of a single focal company in the chain, related to disturbances and interruptions in the physical flow in the supply chain, could be structured and described on a general level. Only economic risks are considered.

The paper is based on a literature review and some case studies. The *literature review* was focused on articles and reports/books on supply chain risk management and related areas. There are one main *case study* (Beta) and two smaller ones (Alfa and Gamma). The author has spent five weeks on the floor in two of the factories of Beta.

One basic assumption in the model is that the supply chain can be divided into three "parts" named: Demand side, Production and Supply side. Another assumption is that there exists a need to analyse the supply chain flow-related risks both from the perspective of the single company in the chain and from the perspective of the supply chain of which it is a part.

Three existing cases illustrate the use of the model. Finally, weaknesses of the model are discussed and some possible directions for further elaboration are presented.

Key Words: Business continuity management, Conceptual model, Disturbances, Interruptions, Resilience, Risk, Risk-handling, Risk management, Supply chain risk, Supply chain management, Supply chain risk management, Vulnerability.

1. Introduction

1.1. Background

Risk is defined by The Royal Society *"as the probability that a particular adverse event occurs during a stated period of time, or results from a particular challenge"* (Risk: Analysis, Perception and Management, 1992, p.2). To be able to come to grips with risks, risk management is needed. The same source defines *risk management* as *"the process whereby decisions are made to accept a known or assessed risk and/or the implementation of actions to reduce the consequences or probability of occurrence"* (Ibid, p.5). Formulated in another way: *"Risk management means taking deliberate action to shift the odds in your favour"* (Borge, 2001, Chapter 1).

Company risks of different kinds have received increasing attention during the last decade both in media (Simons, 1999) and as a research topic. In some countries, new legislation has been introduced making it compulsory to include risk assessment information in the annual report.

This paper focuses on the *supply chain flow risks* where *risk* is defined a*s an event with negative economic consequences*. The chain of transport and storage activities from first supplier to end customer has changed character over the years, and gradually developed from a step-wise chain via a logistical chain into a supply chain (Cooper, Lambert & Pagh, 1997). *Competition* is no longer between different individual companies but *between different supply chains* offering similar products to an end customer. Consequently, the focus ought to be on the supply chain and not on the individual company. The problem is that the supply chain does not exist from a legal point of view and hence the supply chain cannot take actions – only the individual companies in the chain can act. With competition changing from companies to supply chains, it has become very important for the individual company to be a "member" of a competitive supply chain that gives the company a fair share of its surplus. That will not happen by itself. It has therefore become essential for the individual company to "create its own" supply chain alternative, i.e. to find out what consequences different design alternatives have for the competitiveness of the supply chain and the company, and to actively promote supply chain design alternatives with high competitiveness. The individual company in the supply chain needs to look at the consequences for the competitiveness of the supply chain as well as its own competitiveness as an individual independent company in a supply chain setting – the individual company must thus have both *a company perspective* and *a supply chain perspective* simultaneously.

So far, short-term operational efficiency issues seem to have dominated this design work. But every supply chain design alternative also includes risks of different kinds, and the supply chain tends to be increasingly vulnerable. Many firms that earlier realised that the biggest opportunities to increase their competitiveness did not lie in improving their internal efficiency but in supply chain design and integration are now realizing that the biggest risks to the company are not within the company itself but in its dependency on the supply chain. Disturbances in one link of the chain could easily spread to other links in the chain (domino effects). In some situations the negative economic consequences tend to grow worse for each link, and we can here talk about *escalating domino effects*. In combination with often limited liability for the individual link, this means that companies further down the supply chain could actually be much more severely hit than the link where the initial disturbance took place.

A number of *trends* during the last decade have affected the supply chain risk situation. One is that the supply chain should be lean, another that it should be agile as well (Christopher & Towill, 2000; Mason-Jones, Naylor & Towill, 2000). A third trend is outsourcing, resulting in more links in the chain. Single sourcing is still another trend. And of course globalisation. All these trends (and others as well) tend to *make the supply chain more vulnerable.* Christopher & Lee (2004), for instance, have pointed out that *"Managing supply chains in today's competitive world is increasingly challenging".* And the trends change customer demands as well, as e.g. Schwartz (2003) has underlined *"/…/ in many cases, customers are demanding to see proof that a business is ready for trouble before they will award it a major contract or place a company within its supply chain of manufacturing"*.

A number of *severe company events* caused by supply chain disturbances have occurred during recent years. *One example* is Ericsson and the Albuquerque event back in 2000. A minor fire in a production cell, a so-called clean room, at a sub-supplier's plant in Albuquerque, New Mexico (USA), caused by a lightning fire affecting the delivery of electricity for about ten minutes, made the production room unclean and destroyed the production equipment. From a plant perspective the impact was low, but for Ericsson it was huge because the needed component – a radio frequency chip – was single sourced. Even after 6 months the production of chips was only 50 % of what it should have been. Ericsson lost many months of mobile production. The accident also had an impact on Ericsson's decision to withdraw from the mobile phone terminal business (Norrman & Jansson, 2004). *Another example* mentioned in Artebrant et al. (2004) is Nilsson (false name), a Swedish steel producing company selling special steel qualities. Production is complex, includes handling of dangerous material, and has long lead times. JIT-principles were not used except for a few input areas like hydrogen gas, where there was a constant inbound flow. Hydrogen gas, which was single sourced, was bought from a supplier who had built a hydrogen plant just a few hundred meters away from the factory, delivering the gas in a special pipeline. A mistake by some craftsmen doing maintenance work at the hydrogen supplier’s plant caused an explosion in the hydrogen factory and destroyed it completely. Production at Nilsson had to stop totally for a month, and it took several months before it was back to normal again. Their most important customer chose to end the business relation even though Nilsson, with the help of their inventory of finished goods, managed to maintain deliveries. Other deliveries were severely delayed. Sale and market shares were lost.

More and more researchers and practitioners are now realizing the existence of a new risk situation in supply chains (Juettner, Peck & Christopher, 2002; Kajüter, 2003), and the interest in supply chain risk management issues has increased considerably. The increase in supply chain vulnerability has made it necessary to get inspiration for new ways of handling those risks, and Risk Management, which has been an established research area for decades, has become one important area of inspiration. A new research area called *Supply Chain Risk Management* (SCRM), which could be described as the intersection of Supply Chain Management and Risk Management, has developed.

Another relatively new concept and research area is *Business Continuity Management* (BCM). This deals with the issues of how an organisation, after a serious interruption of some kind, will be able to be “back in business" again as quickly and smoothly as possible (Hiles & Barnes, 2001). The tradition has been to focus very much on IT-related risks, but BCM includes all kinds of organizational activity and all kinds of interruptions. Consequently, risks related to the supply chain flow are also treated. BCM and SCRM thus partly overlap.

There exists today no generally agreed definition of supply chain risk management. The definition that will be used in this paper is one that the author has developed from Norrman & Lindroth (2002, p.7) in an earlier work.

> *Supply chain risk management is to, collaboratively with partners in a supply chain or on your own, apply risk management process tools to deal with risks and uncertainties caused by, or impacting on, logistics related activities or resources in the supply chain.* (Paulsson: "Supply Chain Risk Management". Chapter 6, page 80, in Brindley, 2004)

An often-heard opinion is that organisations, as well as society as a whole, will in the future need access to more knowledge about risks and methods/strategies to handle them, and will need to become more proactive (Rasmussen & Svedung, 2000). But as Kloman (2003, p.2), commenting on an Enterprise Risk Management Conference, pointed out *"Most of the speakers agreed that a "common language" for risk is necessary but few reported any progress in reaching this goal"*. There is obviously today a lack of general theories and models about risks including supply chain risks.

Consequently, there is *a need for models* with the help of which risks related to disturbances or disruptions in the physical flow in a supply chain can be identified, structured, described and analysed. Such models are of interest to academia and also to company management, employees, shareholders, local communities, and other stakeholders. In this paper, *one* such *model* – a general conceptual supply chain flow risk model – *is developed*.

1.2. Objective and delimitation

Objective: The objective of the paper is to develop a general conceptual supply chain flow risk model with the help of which risks, seen from the perspective of a single focal company in the chain, related to disturbances and interruptions in the physical flow in the supply chain, could be structured and described. The model should also be able to constitute a basis for deeper studies within the area of supply chain risk management.

Delimitation: Only supply chain flow-related economic risks are considered.

1.3. Method

The paper is based on a literature review and some case studies. The *literature* review focused on articles and reports/books on supply chain risk management and related areas. Some of the findings considering the articles have earlier been reported in a chapter in Brindley (2004). There have been one main *case study*, presented here as case Beta, and a number of smaller ones of which Alfa and Gamma are presented here. During the autumn of 2004, I spent five weeks on the floor in two of the Beta factories. That resulted in three internal reports to Beta and a lot of experience about supply chain flow related risks. Ideas concerning the model developed in this paper existed before I joined Beta, but during my sojourn there they were conceptualised and on some occasions also tested on risk managers of Beta. The model was further developed and related to the literature on my return home.

2. Modelling

According to Borge (2001, Chapter 1) *"/…./ most real-life risk problems of any importance have to be simplified to be solved. The best risk managers are those that can simplify without sacrificing the essentials."* The aim of this chapter is to create a model that is quite simple but nevertheless useful when dealing with supply chain risk issues. The modelling is carried out in *three steps:* First the basic model structure is presented, then different model elements are elaborated in more detail, and finally the complete model is summed up.

2.1. Theoretical base

According to J. Aitken (1998), a *supply chain* can be defined as *"A network of connected and interdependent organizations mutually and co-operatively working together to control, manage and improve the flow of materials and information from suppliers to end users"*[1]. Whitman et al. (1999) define the supply chain as *"a web of autonomous enterprises collectively responsible for satisfying the customer by creating an extended enterprise that conducts all phases of design, procurement, manufacturing, and distribution of products"*.

In a way, no such thing as a supply chain exists because everything tends to be linked to everything else, and in a long-term perspective no starting and ending points can be found. But if we choose the perspective of a single company and a limited time period, which is done in this paper, then the supply chain concept makes sense.

Johnson (2001) mentions two *kinds of risks*, "supply risks" and "demand risks", and Peck et al. (2003, p.44) are talking about four: supply risk, process risk, demand risk and control risk.

Svensson (2002a) discusses the construct of *vulnerability* and identifies two components: Disturbance, and the negative consequence of a disturbance. He further proposes that vulnerability could be measured and evaluated by the help of four principal dimensions: Service level, deviation, consequence, and trend. In two other articles (2002b, 2002c) Svensson discusses based on a rich empirical material vulnerability issues in the inbound and the outbound flows of the firm. The perspective is dyadic relations to and from a single company in the chain.

2.2. A normal supply chain flow

Here the focus is on the physical flow in the supply chain (including its input and output), the economic consequences that this flow creates, and factors in the environment that could influence the supply chain flow and, as a result, change the economic consequences.

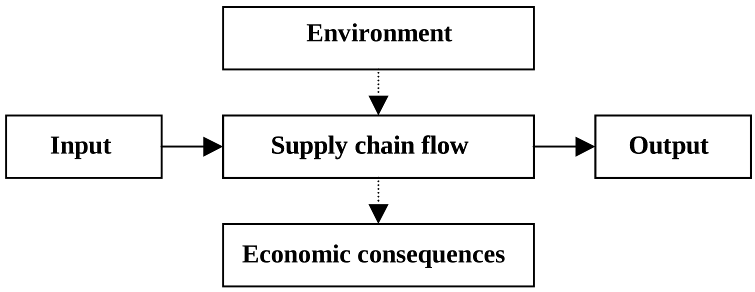

Figure 1: Basic conceptual structure for the modelling.

In the step-by-step reasoning below, a capital letter is used for the first letter in new concepts that will become elements of the model the first time the concept is used.

- The everyday, undisturbed supply chain flow following the plans will here be called the *normal flow*;
- It is all seen *from the perspective of a single company*, here called the *Focal company*, in a *single supply chain* during a *limited time period*;

[1] Reference on page 19 in Christopher (1998).

- The focal company is supposed to produce a *physical product* and to be a link in a *physical flow*;
- It is the focal company that chooses which of its products to study, here called the *Focal product*, and where the supply chain borders are (what's inside the supply chain and what's outside it?). These choices also determine the internal structure of and interrelations in the supply chain;
- The *maximal* supply chain can be regarded as starting where the *Natural resources* in *Nature* are picked up, and ending where the *Final product* is handed over to the *End customer;*
- It is the focal company that defines what is meant by *nature*, *natural resources*, *final product*, and *end customer;*
- The focal company can choose to study the whole supply chain from nature to end customer or smaller segments;
- The supply chain consists of a number of more or less independent companies/organizations (links), each with its own special *value adding* to the final product;
- A supply chain has as its "assignment" to produce and deliver a certain final product that totally or partly serves a specific need for a certain end customer or end customer category;
- A supply chain can thus be defined as all the individual companies/organizations that are engaged through their value adding in *transforming and moving* natural resources from nature into a final product delivered to the end customer;
- Each supply chain has a certain link *structure* and certain *interrelations* between the links. But all this is of no interest to the end customer as long as it doesn't affect the "quality" and price of the final product;
- *Focal components* are all the components needed for the production of the focal product;
- The supply chain is constituted of *three* principally different *"parts"*: Supply side, Production and Demand side;
- The focal company can choose to study something less than the whole supply chain, but all three parts must be included;
- *Supply side* is defined as all the activities that help in transforming the natural resources into the needed focal components for the production of the focal product and moving them to production (production site);
- *Production* is defined as all the activities, like assembly and testing, which help in transforming the focal components into a ready-made focal product;
- *Demand side* is defined as all the activities that help in transforming the focal product from production (at the production site) into an ordered and delivered final product at the end customer;
- Each "part" (supply side, production, and demand side) can consist of one, two or several *parallel links* like several suppliers of the same component or several similar production sites;
- Each "part" can consist of one, two or several *sequential links*. For instance, the supply side can consist of first tier suppliers, second tier suppliers etc.;
- *A transfer point* is a location where an earlier part in the supply chain hands over what has been decided/ordered to a later part in the chain. One such point is where the supply side is handing over the focal components to production, and another where production is handing over the focal product to demand side. There is also a transfer point where

natural resources are handed over from nature to supply side and yet another where the final product is handed over from demand side to end customer.

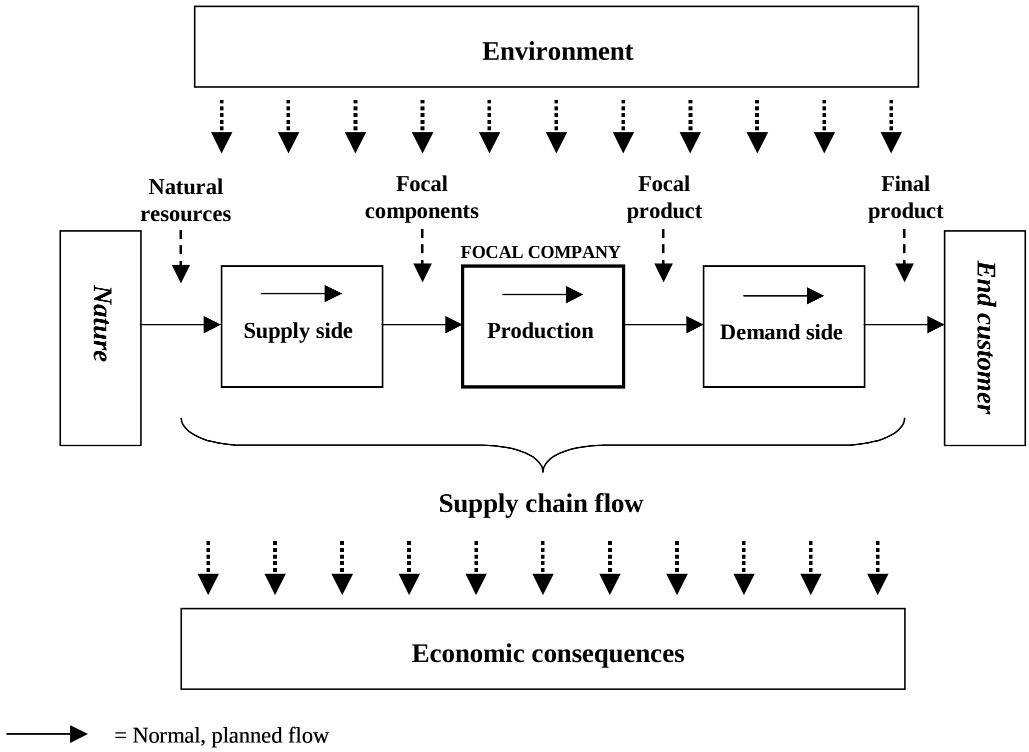

Figure 2: Basic normal supply chain flow model.

2.3. A disturbed supply chain flow

In this paper, however, the focus is not on the normal flow but on disturbances and interruptions in the normal flow. A *Disturbance* is an unplanned, sudden change, usually a decrease, in the normal flow in the chain, which leads to *negative economic consequences* to the focal company. *Interruption* is the situation where there is a 100 % decrease. It can be said to be a special case of disturbance. Hereafter, only the word *disturbance* will be used.

2.3.1. Disturbances

There are *three different types* of disturbances related to the supply chain: disturbances within one of the supply chain parts, disturbances within one supply chain part spreading out of the part, and disturbances into the supply chain. All disturbances except the disturbances within one supply chain part imply that the handover in a certain transfer point has not taken place in the way it was planned.

2.3.2. Natural resources – Nature

Natural resources like raw material of different kinds, including water and air, are input to the supply chain. Natural resources tend to be stable, at least for rather long periods of time, but accessing them in nature could be sensitive. It would therefore be more accurate to talk about the *accessibility* of natural resources.

2.3.3. Final product – End customer

There is usually not just one end customer but a number of end customers – a market. The reaction from this end market to disturbances is what is of interest here. Let us call that reaction end market reaction or just *market reaction*. It could be divided into short-run reaction and long-run reaction.

How then do delivery problems caused by a disturbance affect the market in the short run? In some markets, such as the market for fast food meals like hamburgers, practically no delay can be accepted, while in other markets, like the market for exclusive sports cars, delays of several months might be accepted. The patience of the market decides what the negative economic consequences of delivery problems will be in the short run. *Market patience* is thus one aspect of market reaction.

What then are the long-run effects? The customers' opinions about the long-term ability of the supply chain to deliver on time is reflected in their confidence in the supply chain. How does a disturbance affect this confidence? Do the customers dare to continue to do business with that supply chain or will they change to another supply chain? And if they choose to continue the relationship, will they demand a price cut to compensate for the diminished confidence and the risk-handling actions they may have taken, like increasing their buffer stocks? *Market confidence* is thus another aspect of market reaction.

Delivery problems caused by a disturbance do not necessarily lead to a negative market reaction. If the supply chain manages to handle a live disturbance satisfactorily, that shows the market that the supply chain has a good general awareness of disturbances and is well prepared to handle them, which could in fact lead to an increase in market confidence. On the other hand, as the example with Nilsson – the steel producer – illustrated, a disturbance that never harms the customer can nevertheless hurt market confidence.

2.3.4. Negative economic consequences

The negative economic consequences have to be considered on two levels: the supply chain level and the focal company level. This does not mean that the focal company and the supply chain are identical – it simply means that the focal company needs *both* to observe the disturbance risks from its own narrow perspective – *a focal company perspective* – and from the perspective of the whole supply chain – *a supply chain perspective.*

The focal company perspective is needed simply because it is the focal company that is our prime focus. The supply chain perspective is needed because the competitiveness and well being of the focal company is very much linked to the competitiveness of that supply chain of which the company is a part. If this supply chain is not competitive, then there will be no business for the focal company in the future (at least not in that supply chain). The two perspectives might, however, have different importance in different situations. If, for instance, the focal company is only loosely integrated in the supply chain and could easily change over to another supply chain, then the supply chain perspective will be of less importance than if the company is strongly integrated with other supply chain links and no alternative supply chain exists.

From a focal company perspective we are interested in the impact of a disturbance on the business value of the focal company. Business value impact could be defined as the net sum of changes in costs, including capital costs, and revenues, like additional freight costs for express deliveries, and lost sales because of late deliveries. So instead of negative economic consequences, we should talk about *negative focal company business value impact*. A corresponding argument for the supply chain perspective gives us the concept *negative supply chain business value impact*.

2.3.5. Environment – risk-influencing factors

What is there in the environment of the supply chain flow that could affect the supply chain risks? One such factor is obviously the *product* itself (e.g. its complexity). Another is the *processes* that are needed to transform natural resources into a final product. A third factor is the *structure* of the supply chain (number of links, for instance). Still another is the *rate of change* in the environment, because the faster the rate of change, the bigger gaps there tend to be between risk exposure and risk handling. The reason is that with higher rate of change it becomes more difficult to get an up-to-date and accurate "picture" of the risks, and it is also more difficult to find and implement risk-handling methods that could take care of those risks. The focal product belongs to a certain line of business, and the rate of change in that trade is of special interest. Finally, the *management systems*, which through the exchange of information and money keep the different links in the chain integrated, are also of interest. Some of the systems have specific risk tasks, and those systems, which we could call risk management systems, are of particular interest here.

2.4. The general supply chain flow risk model

If we sum up the discussion above, we will obtain the following general conceptual model. In the figure below the normal, planned, flow is illustrated by solid arrows, while the flow that is subject to disturbances is illustrated by arrows divided into two parts, with dots between the parts. All those arrows are one-way arrows, although the actual flow, in probably all the cases illustrated by the arrows, goes both ways. The arrows thus only illustrate the main direction of the flow. In this way the complexity of the model can be reduced.

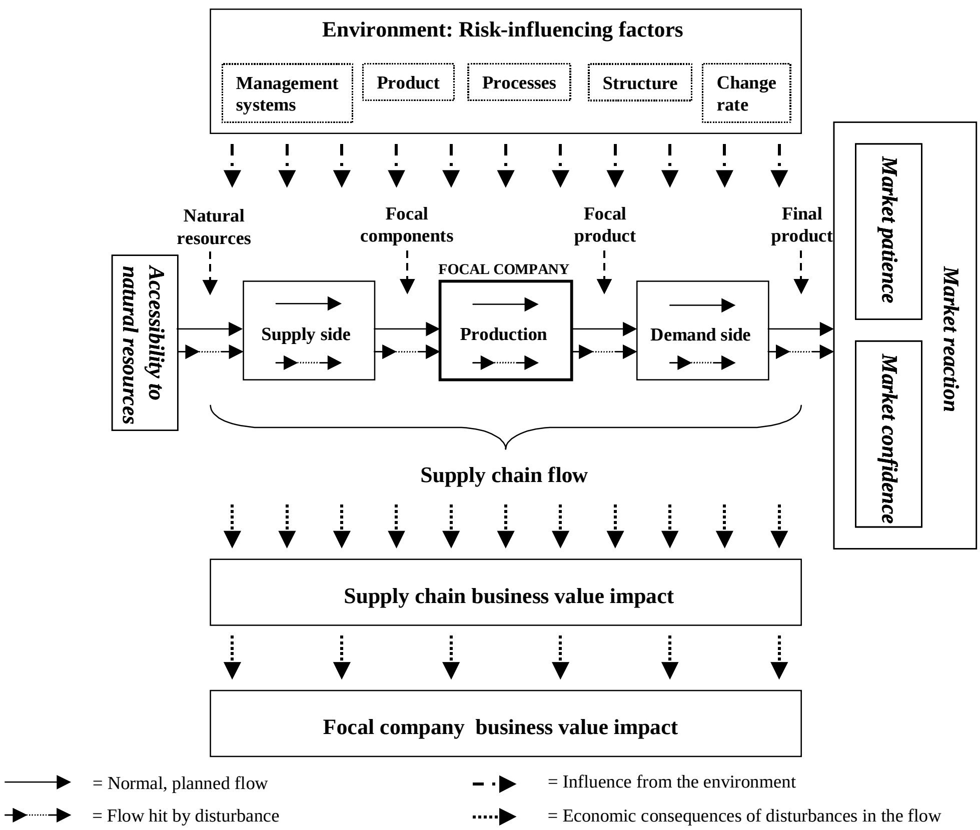

Figure 3: The general conceptual supply chain flow risk model.

2.5. Elaborating the risk concept

In section 1.1, risk was defined "as the probability that a particular adverse event occurs during a stated period of time, or results from a particular challenge", and in section 1.2 a delimitation to only supply chain flow-related economic risks was presented. In the earlier parts of this section, a general supply chain flow risk model was developed. As a consequence, "particular event" now acquires the meaning of a change in the supply chain flow caused by a change in its environment, and "adverse" a negative value impact on the focal company and/or its supply chain. *Supply chain flow risk* can therefore now be defined as *a change in the supply chain flow, caused by a change in the environment of this flow, with negative value impact on the focal company and/or its supply chain, and the probability that this will happen.*

2.6. Risk influence – a few examples

The degree of *multiplicity* is important for the supply chain risks. On the supply side, multiplicity could mean that there are several suppliers of the same component – either actual suppliers or potential suppliers. In production, multiplicity could mean that there are several parallel production units manufacturing the same product or similar products. On the demand side, multiplicity could mean that there are several distribution alternatives for delivery to the customer. The existence of *redundancy* is also important. Two examples are buffer stocks and slack in lead times. Overcapacity, for instance in production or distribution, is a third example of redundancy. Finally we could consider *product assortment links*, which means that the sale of one product in the assortment is dependent upon the sale and delivery of other products in the assortment. So if there are delivery problems with one of the linked products, sales will go down for the other products in the assortment as well. To actively change one or several of the risk-influencing factors in order to reach a desired change in supply chain risks would be to employ *supply chain risk management*.

3. Illustrative cases

The three illustrative cases have been chosen so that they represent different supply chain risk profiles. The cases are in existence at present, and no facts have been changed. They are, however, anonymous. Some facts have also been omitted.

3.1. The Alfa case

Alfa is a big company operating on the European market within the chemical-technical trade. It has a number of production units around the continent. Input to the product is different types of basic chemicals; the product and the production process are relatively simple. The rate of change in the *environment* is moderate. Alfa is mainly engaged in the production part of the supply chain, but to some extent also in the distribution and selling of the product. The market consists of both industrial buyers and private households. Here, only that part of the company serving the private households (the consumer market) is considered.

Risks linked to *market patience* are neither high nor low. Customers could easily change over to another supplier. Delivery problems would certainly mean lost sales for the period with delivery problems, but since it is easy for a customer to change back as well, sales might rapidly go back to normal again as soon as the delivery problem is solved. Risks linked to *market confidence* are low, because of the ease of the customer to switch over to another supplier and to switch back again. But there is always the risk that the customer liked the product of the competitor better than Alfa's. Delivery problems in one period are therefore likely to have some impact on sale in the following periods.

The different products are sold and used more or less independently of each other. On the *demand side*, however, there are risks linked to the transportation and storing of the product, but these are only minor risks since each transport unit has limited size and storage is distributed among many premises.

Production means mixing different chemicals according to a certain prescription, tapping the mixture in tanks or cans and labelling it. Most of the products are standard products, where the same product is bought by a number of different customers. The same or similar type of product is produced at several sites and normally in 1-shift. No unique, advanced machineries or specially designed premises are needed, but some of the chemicals are highly flammable and have to be treated with great care. A fire starting in one part of a production unit can also easily spread to other parts of the unit. A fire will, despite insurance policies in effect, cause economic losses. Fire is a real danger, and some production units have their own fire brigade.

The different chemicals needed for production are always available on the supply market. *Supply side* risks are therefore limited. But Alfa does not have to consider the supply risks on a daily basis at all, since they have deals with their suppliers based on VMI and full economic compensation for shortages. So if there were to be a shortage of some chemical, Alfa will be compensated by the supplier for all the negative consequences that this shortage might have for Alfa. The needed chemicals are basic chemicals, and access to the *natural resources* necessary for producing those chemicals is unlimited – but price could change.

3.2. The Beta case

Beta is a big international company operating on a world market with advanced IT-based products for industrial use. The rate of change in the *environment* is high. A number of different products are produced, but one is economically dominant, and that product, here called product x, will be focused upon. Input to product x is a number of very advanced components, some of which are produced at different supply units within the company, and some of which are bought from outside. Several parallel production units exist, but most of the production of product x takes place in one of the production sites. Beta takes care of all the marketing of the product and also its distribution.

Market patience related risks are probably moderate to low. There are several other suppliers of product x on the market, but it is not so easy for a customer to change over to another supplier (or to change back), so the customer is in the short run locked up to a certain supplier. *Market confidence* related risks are probably very high. Since a customer is closely tied up to its supplier, and since product x is quite expensive, it is very important for the customer to have confidence in the supplier's ability to deliver. If this is not the case, then the customer will probably not dare to do business with the supplier.

On the *demand side* there are certain product assortment links, meaning that the effects of a disturbance passing through the demand side will be increased because other products will be affected as well. No buffer stocks exist because you cannot have a buffer of final products in a situation where each copy of the product is tailor-made.

All copies of product x are produced according to customer order specification and are more or less unique. Certain buffer stocks of components exist in the *production* units. The production process can be divided into assembly, downloading of software and testing. Assembly uses standard equipment, but the other two production steps need access to unique, advanced equipment. This is a clear risk, especially as such a great amount of the total production is concentrated on one of the production sites.

On the *supply side* we can conclude that some of the requisite components are standard components but that most of them are expressly developed for product x. Some of those unique components are single sourced, and this constitutes a clear risk. The *natural resources* necessary for producing those components, however, are unlimited.

3.3. The Gamma case

Gamma is a medium-sized company producing high-priced electronic consumer products of good quality with an advanced design. The market consists of a number of countries primarily in Europe. Input can be divided into electronic components and design-related components. Production consists of assembly and testing. The electronic components in the product have a high rate of change, while the design components change much more slowly. Gamma is engaged in designing, producing and marketing their products.

Most products are built to customer order and are more or less unique. Probably, the consumer already has a similar product that provides the same basic function as the one he has ordered. *Market patience* is therefore quite high and the risks low. Repeated delivery problems would probably have some negative effects on *market confidence*, but generally the disturbance-related risks are also quite low here.

The products are sold through special shops that only sell Gamma products and have exclusive selling rights within a local area. The different products are sold more or less independently of each other. The risks on the *demand side* are, in other words, limited.

Production is concentrated to only one big production site working in 1-shift, and usually has spare capacity. The production unit thus has a considerable overcapacity and any delays caused by minor disturbances could easily be handled. In the production process, mainly standard equipment for assembly and testing is used, and the premises are normal factory premises. If the factory were to be totally destroyed, production could therefore be started up in another site after a few weeks.

On the *supply side* we can note that components related to the design are unique but not particularly difficult to produce, and alternative suppliers can be found. All the electronic components are standard components of good quality. Gamma is a small buyer of electronic components, but since they are prepared to pay well for those components they are sure to get them as long as there are any on the market to buy. Finally, we can observe that the *natural resources* necessary for producing the components are unlimited.

3.4. Summing-up and commenting

Summing-up the discussion for *Alfa* we can conclude that risks linked to the supply side and to the accessibility of natural resources are very low. Risks linked to demand side and market reaction are low. Risks linked to disturbances within a single production unit, however, are very high. But those disturbances do not have to reach the end customer because there are other production units within the company with the same or similar products and production equipment that could take over the production – especially since a production unit normally is only running 1-shift. By adding overtime or more shifts, production capacity could rapidly be raised. Production costs will become higher, but customers will get their products on time and consequently revenues will not be affected. For Alfa, then, the total risk related to disturbances in the supply chain can thus be said to be *moderate*.

Beta is exposed to several serious risks. One is caused by unique, single sourced components. Another results from the concentration of production to mainly just one unit, in combination with the need of unique advanced production equipment. A third risk relates to the fact that product assortment links exist, but there are no buffer stocks of final products. Finally, market confidence is critical because it is very likely that there will be a considerable negative market reaction to delivery problems. The total risk related to disturbances in the supply chain is thus *very high*.

For *Gamma* we can conclude that risks in production are limited and so are risks related to other parts of the supply chain. The total risk related to disturbances in the supply chain is therefore *low*. Gamma is, however, exposed to quite large risks, but these are not related to the supply chain flow but to design. Advanced, bold design is the prime competitive advantage of the company, and every introduction of a new product assortment based on a new design concept is critical .Thus Gamma could never in advance be sure of market reaction.

These cases have shown that *the developed supply chain flow risk model is useful* in structuring and describing disturbance-related supply chain risks. The cases have further illustrated that *the risk situation differs* a lot from supply chain to supply chain when it comes to the total risk in the supply chain as well as to the risks related to different parts of the chain. Finally, the Gamma case illustrates that the most serious risks could very well exist *outside* the supply chain flow.

4. Conclusions

4.1. Use of the model

In this paper *a conceptual supply chain flow risk model* has been developed with the help of which risks related to disturbances in the physical flow in a supply chain can be structured and described on a general level. The model helps in treating supply chain risk issues systematically. The model can also be used as a "tool" to start discussions about supply chain risk issues, which could give information of perceived risks and ideas on how to handle those risks.

Within marketing there is a concept called "channel captain", meaning that one of the companies engaged in the marketing and distribution of a product or group of products dominates for one reason or another (Smith 2003). That company is the one that takes most of the strategic decisions for the marketing channel as a "unit", although the channel might consist of several independent companies. Correspondingly, there are cases where a single company in a supply chain dominates the supply chain. We could here talk about a *"supply chain captain"*. In such cases, a supply chain perspective is obviously of great value to that company. But also in situations where the single company has very little influence on the supply chain, it could be valuable for the company to look at the supply chain-related risks. There are always actions to take within the company itself to reduce its supply chain-related risks, and if those actions are not enough to create an acceptable risk level, in most cases there is the possibility to change over to another supply chain. And there is always the option of simply leaving the market.

The user of this model is primarily the individual company in the supply chain, but it could also be a supply chain group, i.e. some of the supply chain members together, or the total supply chain, i.e. all the supply chain members together. The last alternative is probably seldom the case unless the supply chain is very uncomplicated with few links. But the second alternative is relevant, not at least regarding the background of the ideas of partnership and closer relations between certain supply chain members.

4.2. A critical look at the model

This model is based on a number of *assumptions*. One is that of a physical product and a physical flow linked to that product. The model also takes for granted the existence of an x-formed flow in the supply chain where a supply side, production and a demand side can easily be identified. If the supply chain studied does not fulfil those assumptions, the usefulness of the model becomes lower or even nonexistent.

4.3. Expanding the use of the model

The supply chain risk model can be expanded in different ways. Only a few examples of possible further studies will be mentioned here:

- *Risk specification:* Risk, in the model used, is as a general concept, but it would be interesting to specify risk in a number of dimensions to be able to describe in greater detail what could go wrong in different situations – such a specification would probably also make it easier to find suitable risk-handling solutions;
- *Valuation:* By putting values on the risks for the different "elements" in the model and by adding calculation rules, a value for the total supply chain risk can be estimated. However, in most situations it is probably difficult to find real values, e.g. the real impact value of a disturbance. Working with different indexes could then be a suitable alternative;
- *Risk-handling methods:* A few examples of risk-handling methods were mentioned in 2.5. Many more exist, and it would be thrilling to look at each of them and discuss their usefulness for the handling of different supply chain risks;
- *Management:* If we have, on the one hand a "way" of applying values to individual risks and, on the other hand, knowledge about the different risk-handling methods and how they affected the risks, then we could analyze how different risk-handling methods like increasing the buffer stock or changing from dual to single sourcing would affect the individual risk values as well as the total supply chain risk value.

4.4. Final comments

For many reasons, supply chains and the individual companies/organisations in those chains today tend to be more exposed to risks and new kinds of risks than previously. It is therefore reasonable to believe that *in the future there will be an increasing interest in supply chain flow risk issues*, including modelling, both as a practical application and as a research area.

The link in the chain that has the best possibilities to handle a risk, e.g. by taking preventive measures, seldom has the motivation to fully do so simply because the main negative consequences of a disturbance spreading to other links are often taken by those other links and not by the link that "caused" the disturbance. This *lack of incentives* makes the supply chain more vulnerable, and consequently less competitive – at least in the long run – than it would otherwise have been. What is needed is the implementation of a *"disturbance causer pays-principle"*, like the "polluter pays-principle" that exists within the environmental area. Implementation of such a principle for the focal company on e.g. the supply side would mean that there were two equal alternatives. Either the flow is normal and the focal company can hopefully make a profit out of it, or the flow is disturbed and the focal company can get full compensation from the disturbance causer, e.g. a supplier not delivering on time, for the negative economic consequences that the disturbance has caused it, including lost profit. The two alternatives would be "equal" and the focal company indifferent. This *"indifference principle"* can be said to apply in the case of Alfa on the supply side, but that kind of agreement seems to be an exception. The incentives for the individual link in the chain to take actions that would reduce the overall supply chain risks are simply seldom present today. It is therefore necessary for the individual company itself to pay attention to the disturbance-related supply chain risks in order to protect itself both from the direct negative consequences and from the indirect ones. The model developed in this paper could hopefully be of some assistance when analyzing the situation – both from *the perspective of the individual company* and *from the perspective of its supply chain*.

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