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Including product designers in the consideration of resource criticality – an approach from a business perspective

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Abstract

Increases in the price and number of resource supply bottlenecks can have far-reaching consequences for mechanical engineering companies. The consideration of supply risks is of growing importance. This paper discusses the role of product designers when considering the criticality of resources from a business perspective, the potential to be realised when including them in the process, and important aspects for holistic consideration of the criticality issue in companies.

Keywords: Criticality, supply risk, product design, procurement, risk management

1 Introduction

Increasing resource prices and supply bottlenecks can have grave consequences for manufacturing companies. The causes can be found in several value-added steps. Consideration of the resource's supply risk, or 'criticality', plays an increasingly important role.

Part of this topic is discussed in various disciplines, e.g. in the field of supply chain risk management. Although product designers determine the product properties and thereby influences the needed resources, their role in existing approaches often remains unclear. Inclusion of the designer in the analysis of and reduction in resource criticality creates potential for companies that has not yet been realised.

This paper discusses the role of product designers when considering resource criticality from a business perspective and the potential when they are included. Existing approaches of different disciplines are analysed for the extent to which they cover resource criticality and involvement of product designers. Important aspects for holistic implementation of resource criticality in companies are derived and the expected benefits are discussed.

2 Understanding of relevant terms

Resource criticality largely depends on stakeholder perspective. This paper focuses on the perspective of mechanical engineering companies. Relevant terms are introduced in the following sections to create a common understanding.

2.1 Resources

In public debate on criticality, the term ‘resource’ is usually equated with the term ‘natural raw material’. From the perspective of mechanical engineering companies, exclusive consideration of natural raw materials is insufficient. To accommodate the business perspective, an extended understanding of resources was introduced in (Link, Kloberdanz, & Denz, 2014) and is used in this paper. According to this, a resource can be a physical material or energy that is required to operate a process. Thus, a manufacturing company would consider everything purchased from external suppliers to facilitate the manufacturing of its products as a resource.

Resources can be either natural or technical. Technical resources have been extracted from nature and processed by humans, e. g. technical materials, electrical energy, operating supplies, semi-finished products and components. They are required to possess particular properties to enable fulfilment of product function during the use phase. Thus, when discussing criticality of resources, technical resources as well as natural resources should be considered.

2.2 Criticality of resources from a business perspective

Companies have to ensure availability of their resources to enable uninterrupted production of their products. Short-term events can quickly change this availability as it is not always possible to forecast supply interruptions. Therefore, criticality is discussed from the perspective of risk, more precisely, supply risk.

Using the general risk definition used in the field of risk management (e.g. Brühwiler, 2001; DIN EN 60812:2006-11, 2006; ISO 31000, 2009), criticality can be understood as a two-dimensional issue: the likelihood of occurrence of a supply bottleneck and the consequence of this supply bottleneck. The dimensions of criticality have been established in many studies. However, which resources should be considered and when they should be categorized as critical often depends on the stakeholders involved.

2.2.1 Likelihood of occurrence of a supply bottleneck

There are many different effects which might have an impact on the supply chain and therefore an effect on the availability of resources, resulting in a supply bottleneck. These effects have been analysed and discussed in many, mostly empirical, studies (e.g. Moder, 2008). Examples of such effects are bans on exports, coupled production, high demand, accidents and natural disasters. They can occur at various value-added steps within the resource provision phase. However, not all of these effects that occur somewhere in the supply chain result in a bottleneck (see also Link, Kloberdanz, & Denz, 2015).

To assess the likelihood of occurrence of a supply bottleneck, several criteria can be used. If a resource can only be produced by one company, the likelihood of a supply bottleneck is much higher than if there are several manufacturers. An accident during the supplier’s production would cause a bottleneck of the resource, due to there being no alternatives. Aspects such as complexity, structure and length of the supply chain, geographical location of suppliers, exclusiveness and complexity of the resource, and complexity of the manufacturing process may also have an impact.

Frequently, the availability of a resource is determined and limited by requirements. This could be, for example, specific dimensions of components (e.g. a bearing with either an extremely large or extremely small diameter). Hence, evaluating the resource generally is insufficient. All relevant and specific properties of the resource must be considered when analysing the likelihood of a supply bottleneck occurring.
The likelihood of a supply bottleneck also depends on stakeholders and can vary with the geographical location of a company. For example, the conditions of a Chinese and a European company dealing in rare earth elements might be different. In the case of an export restriction of unprocessed raw materials, availability for the European company would probably be greatly limited and the Chinese company would not necessarily be affected.

2.2.2 Consequence of a supply bottleneck

The second dimension concerns the consequences when a resource supply bottleneck actually occurs. Here, too, criteria can be used to assess impact on supply risk.
The significance of a supply bottleneck greatly depends on the availability of a substitute resource. If the resource is easily replaceable, the consequence of a supply bottleneck is relatively small. The performance, availability and costs of a possible substitute should be compared to the original resource (Graedel et al., 2012).
Substitutability depends on the resource's role in the product. Many product properties depend on the properties of a resource, which can exacerbate its substitutability. For example, an engine with a special structural form could, due to its shape and dimensions, influence many more product components. A replacement of the engine would lead to a major modification effort. The same applies to the use phase. High dependency of product performance on particular resource properties can reduce substitutability.
Substitutability also depends on the specificity of the resource. For a standard part, a new supplier can probably be found quickly, so the consequence of the bottleneck is not critical. If a resource is exclusive to one company, a new supplier might need to maintain specific process know-how first. Proprietary rights issues might also occur.
The consequence of a supply bottleneck also depends on its duration and how well production delays can be tolerated by the company. As a supply bottleneck often first results in a price increase, the consequences vary in line with the amount of resource required to manufacture the product. Another factor, from the company perspective, is the ability to pass on cost increases to the customer, in which case the manufacturer would assess the significance as being lower.
The consequences for the company can also be considered, though it is not the focus of this paper.

3 Similar approaches in different areas of research

Criticality is not a completely new topic; it is partly considered in approaches of various disciplines. Based on a literature review, these existing approaches and their consideration of criticality will be discussed from a business perspective.

3.1 Criticality studies

There are a growing number of studies that examine resources for their criticality from global, national and corporate perspectives (e.g. Duclos, Otto, & Konitzer, 2010; Erdmann, Behrendt, & Feil, 2011; Graedel et al., 2012). As discussed in (Link, Kloberdanz, & Denz, 2014), these studies are not sufficient to criticality assess resources from a business perspective, as they are mainly focussed on natural resources, particularly metals and minerals, not technical resources. Macroeconomic approaches can only make broad statements concerning the supply risk of resources. Existing criticality studies can only provide orientation; further and deeper analysis is necessary.

3.2 Supply chain management

Different understandings of supply chain management (SCM) exist in literature. Cooper et al. give a general definition, "Supply chain management is the integration of business processes from end user through original suppliers that provides products, services and information that add value for customers" (Cooper, Lambert, & Pagh, 1997). Hence, this is an overall approach that includes a varying number of internal and external stakeholders. System borders range from the sole consideration of the immediate supplier and customer of the company, to multiple layers of suppliers and customers, to consideration of all of the organizations involved in the value creation process (Mentzer et al., 2001).

The main objective of SCM is increasing competitiveness. It is assumed that product competitiveness is not just the responsibility of one company, but the entire supply chain (Stadtler, 2010). Further advantages include the synchronizing of customer requirements and a reduction in the total amount of resources used along the supply chain (Cooper, Lambert, & Pagh, 1997). The tasks in SCM range from arrangement of value-added chains, to execution of operative processes and communication between companies, to definition and realization of common objectives (e.g. Bogaschewsky, 2003).

In SCM, different functions of a company work together: marketing, research & development (R&D), logistics, production, purchasing, and finance (Lambert, 2008). Although R&D is a stakeholder in SCM, it is not yet included systematically. The focus is on the consideration of organizational processes, including purchasing. Current suppliers and cooperation with them is the main interest. In addition, optimization of the entire supply chain inside system borders is considered.

3.3 Risk management and supply chain risk management

Risk management is applied to different systems to determine possible obstructions to the accomplishment of system goals with the aim of being able to act accordingly (Brühwiler, 2001). A precondition for effective risk management is continuous integration into planning and control processes (Kajüter, 2015).

Risk management is also linked to purchasing at a company or supply chain level. In the latter case, it is called supply chain risk management (SCRM). When considering the entire supply chain, more effective risk measures, and therefore reduced risks and costs for supply chain stakeholders, are expected (Kajüter, 2015).

There are three approaches for the integration of the supply chain perspective into the risk management process: Risk management with supply chain orientation; risk analyses in the supply chain; and supply chain risk management (Kajüter, 2015). In practice, systematic cross-company risk management (the last approach) seems to be the exception (Christopher et al., 2011).

Many models exist that explore the procedures involved in the risk management process (e.g. Hallikas et al., 2004; Sinha, Whitman, & Malzahn, 2004), which can be summarized as the following phases: risk identification, risk assessment, decision and implementation of risk management actions, and risk monitoring. Typical measures in SCRM focus on purchasing, e.g. sourcing strategies, supplier contracts, price agreements, and taking out insurance policies.

The principal analysis process in risk management seems to be transferable to criticality. However, in SCRM, the supply situation is considered company-wide. Therefore, there is no reference to one product. Additionally, the product designer is only partly involved in the SCRM process.

3.4 Purchasing

Purchasing usually means all actions required to secure provision of resources (Kummer, Grün, & Jammernegg, 2009), using the same understanding of resources described in Section 2.1. An important goal is ensuring that the resources are available in the necessary amounts, at the right time, in the right place, and that they have all the required properties (Bichler et al., 2010). The lowest possible costs and highest possible supply reliability are sought. For purchasing, literature often differentiates between strategic and operational levels. The resulting purchasing tasks include demand planning, sourcing, and assessment and development of suppliers (Melzer-Ridinger, 2008). In some instances, early warning systems for the detection of supply bottlenecks are discussed.

As purchasing and product design are commonly carried out sequentially and separately, the company procurement department has hardly any influence on product development. The procurement department's scope for action is limited and measures to reduce supply risk generally focus on corresponding purchasing instruments, such as sourcing strategies (e.g. single vs. multiple sourcing), types of resource provision (e.g. just-in-time vs. stock procurement), supplier development, and price agreements (Melzer-Ridinger, 2008). Purchasing is not organized by products but by commodities. Thus, product related aspects are either not considered or considered only in a restricted way.

In purchasing related literature, criticality is discussed in a similar way. As an improvement approach, provision of price lists, periodic reports, and building of cross-functional teams are discussed (Melzer-Ridinger, 2008). However, literature does not provide these ideas in the form of methodical approaches. Some approaches that include product development can be found in discussions on early supplier involvement (Section 3.6). However, until now, product development has not been systematically integrated.

3.5 Product design

Product development realizes customer requirements of a product with the goal of developing a marketable and successful product. There are various methods to support product development: generally applicable ones (e.g. regarding requirement engineering or cost management) and methods that achieve specific development goals (e.g. DfX approaches). Within the product development process, the designer mainly determines product properties and consequently the resources needed (Link, Denz, & Kloberdanz, 2015). However, they have only limited knowledge about supply bottlenecks and critical resources. Existing methods only marginally consider criticality, if at all. Companies partly initiate product overlapping projects with the goal of reducing internal part diversity.

3.6 Integration of purchasing and product development

Besides the disciplines discussed, literature also provides approaches that establish a connection between purchasing and product development.

Burt and Soukup, for example, analysed the product development process and defined six points at which purchasing should provide information and support product designers (Burt & Soukup, 1985). They suggest lists of recommended parts, formal reviews, employee rotation, and project teams. They also recommend locating purchasing employees close to development engineers. No further development methods on supporting this cooperation are discussed.

The approaches of early supplier involvement (ESI) are widespread as well. The objective is to integrate suppliers as early as possible into the development process. Several positive effects, such as reduced time-to-market, improved product quality, reduced costs for new products, and enhanced cooperation, are expected (Lakemond, 2006; Petersen, 2003; Wynstra & van Echtelt, 2001). Approaches to realize ESI mostly focus on forms of communication with the supplier and the point of involvement.

Another approach is the building of cross-functional teams, e.g. purchasers and development engineers. They are considered "article specialists" and are responsible for one group of components. On the request of product development staff, they decide whether a component should be newly developed or if a standard part should be used (Wynstra, Van Weele, & Axelsson, 1999).

4 Implementing criticality in a company

4.1 The product designer's role

Criticality is currently considered mainly from the purchasing perspective. However, the product designer also plays an important role. Through their design decisions, the product designer determines product properties and has a major influence on the resources needed. The availability of resources is often limited by the properties of the resource, which can also have an impact on the consequences of a bottleneck. As seen in the literature review, specification of a resource can strongly affect the purchasing team's scope for action and leads to different supply risks.

The designer has explicit or implicit knowledge about which resources and their properties are necessary to provide the expected benefit during the use phase for the customer. Considering criticality early in the product development process could lead to products that are more robust against supply bottlenecks in the supply chain and consequently could lead to significant competitive advantage.

Several measures can be taken by the designer, such as thinking of preferred resources with low criticality right from the start: instead of damage limitation, the damage could be prevented from the beginning.

If the bottleneck-causing properties of a resource are known, the requirements can systematically be questioned and, where appropriate, changed. Independent of the consideration of certain supply risks, the elimination of unnecessary or unnecessarily high requirements of a resource can be pursued, since it tends to effect the scope of purchasing and product development positively.

Easy substitutability of a resource can be sought to quickly react to a supply bottleneck. Reducing the dependency of other components of a resource is an example of a measure to keep upcoming redesign effort low.

Designing modular products is useful, as is internal standardization.

4.2 Criticality consideration in a company

To implement criticality holistically, the following aspects are important (Figure 1):

- Systematic linking and integration of knowledge
- Methodical support
- Continuous process from the beginning.

They are briefly discussed in the following section.

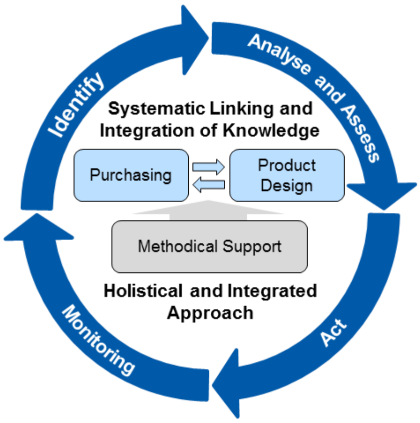

Figure 1. Consideration of criticality as a holistic process in a company.

4.2.1 Systematic linking and integration of knowledge

While determining the resources to be used, the designer often has little information about what the resources contain exactly or which of their properties could limit their availability. In principal, they cannot consider criticality during the development of a product. Because purchasing and product development teams play important roles, their collaboration is extremely important. Their knowledge on criticality aspects is explicit and implicit. Purchasing has knowledge of the supplier situation, available resources, purchasing strategies, etc.; product development knows the product, the resources needed and their requirements. This knowledge should be linked and integrated systematically, raising awareness of criticality and supporting mutual understanding of the other function's challenges. With awareness raised, unnecessary or unnecessarily high requirements might be avoided from the beginning. It is possible to link this process with existing business processes concerning product life cycle management.

4.2.2 Methodical support

To derive measures as holistically as possible and reduce supply risk from the beginning, a detailed understanding of the relation of bottleneck causes and bottleneck impacts is fundamentally important. Four approaches are needed to achieve this and are discussed in the following section.

- *Causes of a supply bottleneck:* Since the availability of a resource is often limited due to a specific requirement of this resource, a differentiated consideration of the resource properties is important. The identified causes form the basis for assessing the likelihood of a supply bottleneck and developing measures to reduce it. To support the designer, deducing bottleneck drivers and availability drivers could be useful.

- *Impact of an event on resource availability:* If a disruption in the supply chain is known (e.g. a natural catastrophe or an export ban), it is important to anticipate the likelihood of it resulting in a bottleneck in the company's resource so that the company can react early.

- *Key parts of the main life cycle processes:* To the customer, the satisfactory fulfilment of the central product functions and use processes is essential. Fulfilment depends on certain resources and their properties, which can also be called key parts. Identifying the key parts can be helpful for systematic standardization and diversification to reduce criticality of resources used. The accepted implementation effort (e.g. monitoring of availability) can be higher for these key parts.

- *Consequences of a supply bottleneck for life cycle processes:* In a resource bottleneck, it might be necessary to resort to resources that have deviating properties. Knowledge of the impact on the product and the use phase is fundamental when estimating the substitutability and evaluating the supply bottleneck's consequences.

The analysis process needs two different methods: one for systemizing and linking knowledge from purchasing and product development, and one for identifying the cause of the bottleneck and the bottleneck impact. The first method could be an adapted version of Failure Mode and Effect Analysis. This could support collaboration between the two business functions. The second type of method is based on properties analysis and process analysis.

4.2.3 Continuous process

The consideration of supply risk should be a continuous process. As well as identifying possible bottlenecks and their analysis and assessment, defining, implementing and monitoring measures are important. Criticality should be considered continuously during the development process, right from the start. While there are significant levers to influence criticality in early product development phases, relevant information on the supply risk is not on hand until later on. Therefore, early estimation on the basis of a reference product can be helpful. Provision of knowledge on criticality of certain resources could lead to advantages in later projects or be transferred to different products in the company. Implementing fundamental milestones in the development process to investigate criticality could be helpful to monitor its consideration.

5 Conclusion

The consideration of resource criticality is highly important to companies. In industrial practice, detecting potential supply bottlenecks and their causes, and what measures can be taken to reduce the criticality of resources, is often unclear. Knowledge often exists somewhere in the company but is not sufficiently linked.

Purchasing deals partly with criticality. Development of products and parts purchasing are usually carried out sequentially and independently. So, purchasing has hardly any influence on product development and the team's scope for action is often limited. Measures to reduce supply risk are usually focused on purchasing strategies so far. The need to improve collaboration and information flow between purchasing and product development has been recognized in some approaches. Nevertheless existing approaches are limited to organizational concepts, such as the formation of cross-functional project teams or provision of price lists to product designers.

In this paper, a holistic approach to implementing criticality in companies is suggested. The basic principle for this is a broad understanding of resources and criticality. The systematic inclusion of the product designer in analysis and reduction of resource criticality would create potential for companies that has not yet been realised. Instead of damage limitation, the damage could be prevented from the beginning.

Systematic collaboration between purchasing and product development teams can bring individual knowledge together. Awareness of criticality can be raised and mutual understanding of the other function's challenges can be supported. With raised awareness, unnecessary or unnecessarily high requirements might be avoided from the beginning.

The systematic analysis of bottleneck cause and impact, as well as the implementation of a continuous process, promotes a sophisticated understanding of criticality within a company. More measures, in addition to existing sourcing strategies, can be derived and implemented in product development processes to proactively avoid supply bottlenecks.

If a supply bottleneck can be identified early on, the company has more time to react and take suitable measures. However, the effort entailed in early detection is not always justifiable. The decision has to be made whether early detection of bottlenecks in a certain resource is worthwhile.

Criticality is predominantly a topic that has to be pursued at a strategic level and has to be operationally implemented. To support this process, appropriate methods and tools are needed that involve purchasing and product development teams and that provide the right people with the required knowledge within the company.

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