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From customer understanding to product understanding: Collaboration with industrial lead users in a B2B context

Magnus Tottie*, Thomas Lager** and Sofia Nordqvist***

* LKAB, 98381 Malmberget, Sweden
** EMINES – School of Industrial Management, Université Mohammed VI Polytechnique, 43150 Ben Guerir, Morocco, thomas.lager@emines.um6p.ma
*** Luleå University of Technology, 97187 Luleå, Sweden

Product innovation will continue to play a strategic role for companies producing high-quality, functional products for customers in the process industries. In the future, creating improved or radically new products will necessitate not only the development of product concepts resting more on an applied research knowledge base but also collaboration with customers. LKAB is a world-leading producer of processed iron ore products for steelmaking. The development of next-generation pellet products in collaboration with lead users presented an opportunity for a single case study in a B2B context. Two customers for present products as well as a technology/equipment supplier were identified as lead users. Using a framework grounded in lead user development, the Quality Function Deployment methodology (adapted to process-industrial use) was used as the facilitating instrument. It is concluded that this modified system will constitute an improved integrated knowledge-based platform for the development of new product and process concepts. It is argued that this development approach could also be applied in other process-industrial sectors serving industrial customers in an open innovation perspective.

1 Introduction

The process industries span several manufacturing industrial sectors (e.g. minerals & metals, pulp & paper, food & beverages, chemicals & petrochemicals, utilities and pharmaceuticals) and thus constitute a substantial part of all manufacturing industry. A key difference between companies in the process industries and those in other manufacturing industries is the former's often long, complex and rigid supply/value chains (Tottie and Lager, 1995). Moreover, the context for innovation differs radically; in the process industries, development takes place in laboratories and pilot plants rather than in a design office, and the final quality of products is often strongly related to available raw material properties. As a result, there is an intimate relationship between product and process innovation, summarized in the idea that "the process is the product" (Rousselle, 2012).

In the future, creating improved or radically new products will necessitate not only an efficient product development work process but also the adaptation of development tools like the Quality Function Deployment methodology (QFD) for process industrial use. The Stage-Gate work process advocated by Cooper (1988b) must today be regarded as a de-facto standard for a formal product development process. The "fuzzy front end" of this process was introduced by Smith and Reinertsen (1991) as the first stages of the product development process, covering the period from ideation to approval to enter the product development stage. In 1988, Cooper found that the greatest differences between winners and losers were found in the quality of such pre-development activities (Cooper, 1988a). One important outcome of the fuzzy front end is a product concept that is usually restricted to a description of the new product idea and associated product specification. In a multiple case study in the area of front-end innovation of non-assembled product development, Frishammar et al. (2012)

recognized that, in the earliest phase of front-end activities, the identification of a "process window" in existing production process technology was also a common practice in which new product ideas were positioned.

The importance of using external information in development has been stressed in a vast number of publications (e.g. Chesbrough and Appleyard, 2007; Chesbrough, 2007) and is generally accepted today. In the process industries, such collaborative behavior is nothing new (Aylen, 2010). Thus, Trott and Hartman (2009) describe those open innovation activities as "old wine in new bottles". Nowadays, even the most capable R&D organization needs to identify, connect to and leverage external knowledge sources as a core process in innovation. Resources from a company's "relational capital" have thus been shown to be important in all stages of the product development process, from the problem recognition and idea generation, through product concept development, to prototyping and testing (Fuller et al., 2011). One approach in customer collaborations and co-development is to integrate lead users into the product development process (von Hippel, 1986). Luthje and Herstatt (2004) initially notice that lead users by definition do not just face any new need but rather recognize needs that most customers in the market will face in the future. Martinez (2014) identifies a need to incorporate the "Voice of the Consumer" at the center of the innovation process as well as a need for the ability to translate subjective consumer needs into objective product specifications.

Product innovation will continue to play a strategic role for companies in the process industries producing high-quality functional products for B2B customers. One such company, LKAB, is a world-leading producer of processed iron ore products for steelmaking. In their development of next-generation pellet products, they selected the QFD methodology as an overall framework and development tool to translate customer requirements into design requirements. The collaboration with lead users in this project presented an interesting opportunity for a single case study of the usability of the methodology in co-development with lead users and in a B2B context. The two research questions (RQ) to be answered in this study are as follows:

- RQ1: What is the general usability of the QFD methodology as a facilitating instrument in the co-development of products with lead users in a B2B context?

- RQ2: What is the specific usability of the multiple progression QFD (mpQFD) system as an overall framework and knowledge-building tool in the pre-development part of product development in process industries?

The paper is organized as follows. First, the lead user development concept for co-development in a B2B context is reviewed and the QFD methodology is introduced. Afterwards, the research approach and the case company are presented. Next, the empirical evidence is presented, focusing on the use of the methodology as a facilitating tool. Finally, the results are discussed in the perspective of generalizing the research results to other sectors of the process industry and concluding with management implications and a research outlook.

2 A frame of reference: lead user collaboration in the B2B context and an introduction to the QFD methodology

2.1 The product development work process

The Stage-Gate system, also known as the Idea-to-Launch process, advocated and advertised by Cooper, must today be regarded as a de-facto standard for a formal product development work process. In his review of the system, Cooper (2009 and 2012) emphasizes the importance of gathering the Voice of the Customer and the importance of the fuzzy front end of the system. The Stage-Gate system was recently studied in a large sample of users and it proved to be an instrument that top-performing companies use often and well (Cooper, 2012). The product development process model in figure 1 is an example of a slightly modified Stage-Gate model that is adapted to a process-industrial context to be used as a template for this study.

The fuzzy front end of product development is the first stage of the new product development process, covering the period from ideation to approval to entering the next stage of product development (the fuzzy front end is designated as pre-development in figure 1). Reid and de Brentani (2004) also show that there is a clear distinction between early and late activities in this part; specifically, early activities are broad, while later activities consist of information collection and concept development (Backman et al., 2007). Product concepts are usually restricted to a description of the new product idea and related product specifications. In a similar vein, a process concept could also be defined (Kurkkio et al., 2011). Backman et al. (2007) advocate that the transition of concepts other than technology concepts also necessitates a contextualization in which the concept is dressed in such a way as to fit a new product development context. In a study by Herstatt et al. (2004), Japanese front-end activities are compared with those of German companies, and it is proposed that Japanese companies rely on more formal approaches to reduce uncertainties during the pre-development part than German companies do. In a follow-up study, Herstatt et al. (2006) conclude that, in addition to knowing customer requirements, the gathered information has to be translated into technical specifications and integrated into the product concept. Verworn et al. (2008) note that *"there seems to be a lack of communication between marketing and technical functions and the customer requirements were not translated into technical language"*; an interesting conclusion that could favor the use of development methodologies such as QFD. In their study on the fuzzy front end as well as on discontinuous innovation improvements, de Brentani and Reid (2012) recommend that management also should provide a decision support system for codifying tacit knowledge, an attribute of the QFD system that so far has still not been properly recognized.

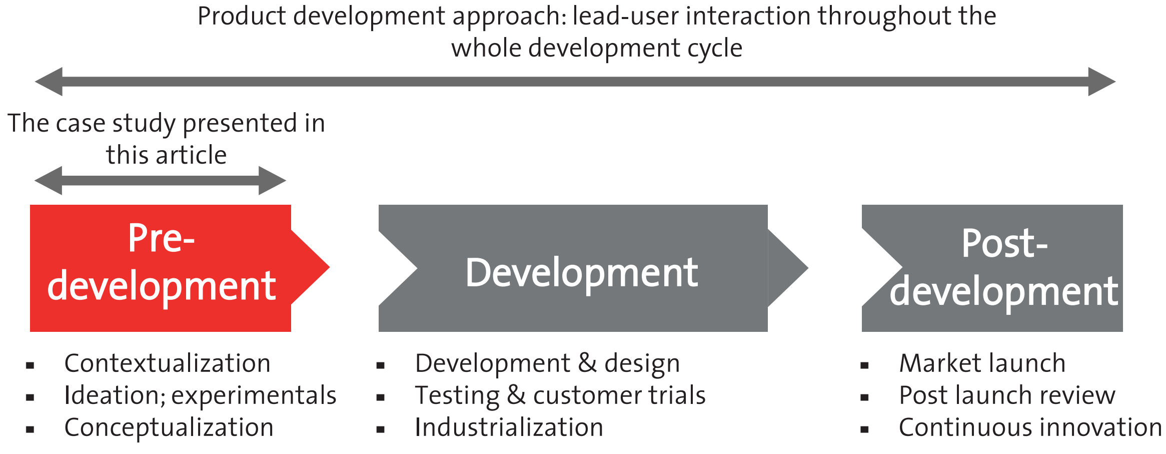
2.2 Co-development in the pre-development part of the product development work process

Toward the end of the eighties, von Hippel (1986) introduced the new development concept of integrating users of company products, processes and services into the innovation work process as "lead users". In the discussion of lead users, it is important to note that they can be individuals, groups or companies that have product needs beyond what is currently available in the general market (Eisenberg, 2011). The idea was grounded in the assumption that consumers, but also industrial customers, often have a limited insight into new product needs and potential solutions since they are constrained by their own real-world experiences. The concept of lead users proposes that this category of product (or process) users are in a better position to provide accurate data on needs related to future conditions. Additionally, the greater benefit a user can obtain from a novel product, the greater his effort to obtain a solution. In this study, we use a slightly modified definition of the lead user concept:

"Lead users are defined as members of a user population who (1) anticipate obtaining relatively high benefits from obtaining a solution to their needs and so may innovate and (2) are at the leading edge of important trends in the marketplace under study and so are currently experiencing need that will later be experienced by many users in the marketplace." (Franke et al., 2006; von Hippel, 1986)

In the identification of lead users, and apart from being a trend leader, it is important that the lead user perceives a mismatch between his needs and the functions or performance of existing products (Luthje and Herstatt, 2004). Both components in this definition later proved to be independent dimensions (Franke et al., 2006). Luthje and Herstatt (2004) initially note that lead users by defi-

Figure 1 The product development work process with regard to integrating lead users. In this study, only the pre-development part of the work process, also known as the fuzzy front-end of product development, is studied.



nition do not just face any new need, but they realize needs that most customers in the market will face in the future. They also point out that lead users frequently play an important role in the development of new products particularly for industrial markets.

The lead user concept is similar to the concepts of co-creation and co-development that are also often used today. Bettencourt et al. (2014) challenge existing marketing practice and express value being created with customers in the context of use. A study by Macdonald et al. (2011) suggests that, in a B2B context, multiple respondents are needed in order to assess value-in-use at the individual as well as the organizational level. In a further discussion of B2B marketing and companies' interactions with other companies, Vargo and Lusch (2011) suggest that this knowledge base should also be used in general B2C marketing. In the active integration of innovative users in the innovation process, chemical and pharmaceutical companies such as BASF and Eli Lilly have successfully used open-source problem solving (Lakhani and Jeppesen, 2007). The findings of Fuller et al. (2011) show that it is the perceived autonomous, enjoyable experience that enables them to come up with superior solutions. The drivers for consumers to engage in co-creation are further studied by Fuller (2010), whereby the results are equally indicating that monetary incentives are not as important as the interactive experience itself.

2.3 An introduction to Quality Function Deployment and the mpQFD system

At the beginning of the seventies, Japan was the birthplace of a new methodology and tool for structuring customer requirements and translating them into design requirements as a new platform for product development (Akao, 2003). The first system, developed by Akao (Akao, 1990; Mizuno and Akao, 1994), is still the dominant system used in Japan. This system's breakthrough occurred in the Japanese manufacturing industry and is often ascribed to Toyota Auto Body, whose use of QFD successfully contributed to solving their problems with low-quality, rusting cars. The system's introduction in the European industry followed during the early nineties, and the first Swedish and European QFD projects in the process industries were reported in the mid-nineties (Tottie and Lager, 1995).

The most commonly used QFD system in other manufacturing industries is often called "the four phases of matrices" (Hauser and Clausing, 1988). Starting with the development of the House of Quality, the customer requirements' WHATs are translated into design requirements' HOWs, which can then serve as WHATs in a consecutive matrix to express the demands on part characteristics and can afterwards be further progressed to the process planning and production planning matrices. This four-stage progression system is, however, not applicable to the process industries as the products of the latter are not assembled components. Additionally, the products and related production processes are firmly interlocked in the process industries, so that product and process innovation must always go hand in hand. Consequently, customer requirements on the product must not only first be translated into design requirements but also, and more importantly, must then be further progressed into the production system as requirements on process capabilities and on raw-material properties. The multiple progression QFD system (mpQFD) used in this project is thus specifically designed to fit process industrial needs (Lager 2005b). The system is illustrated in figure 2.

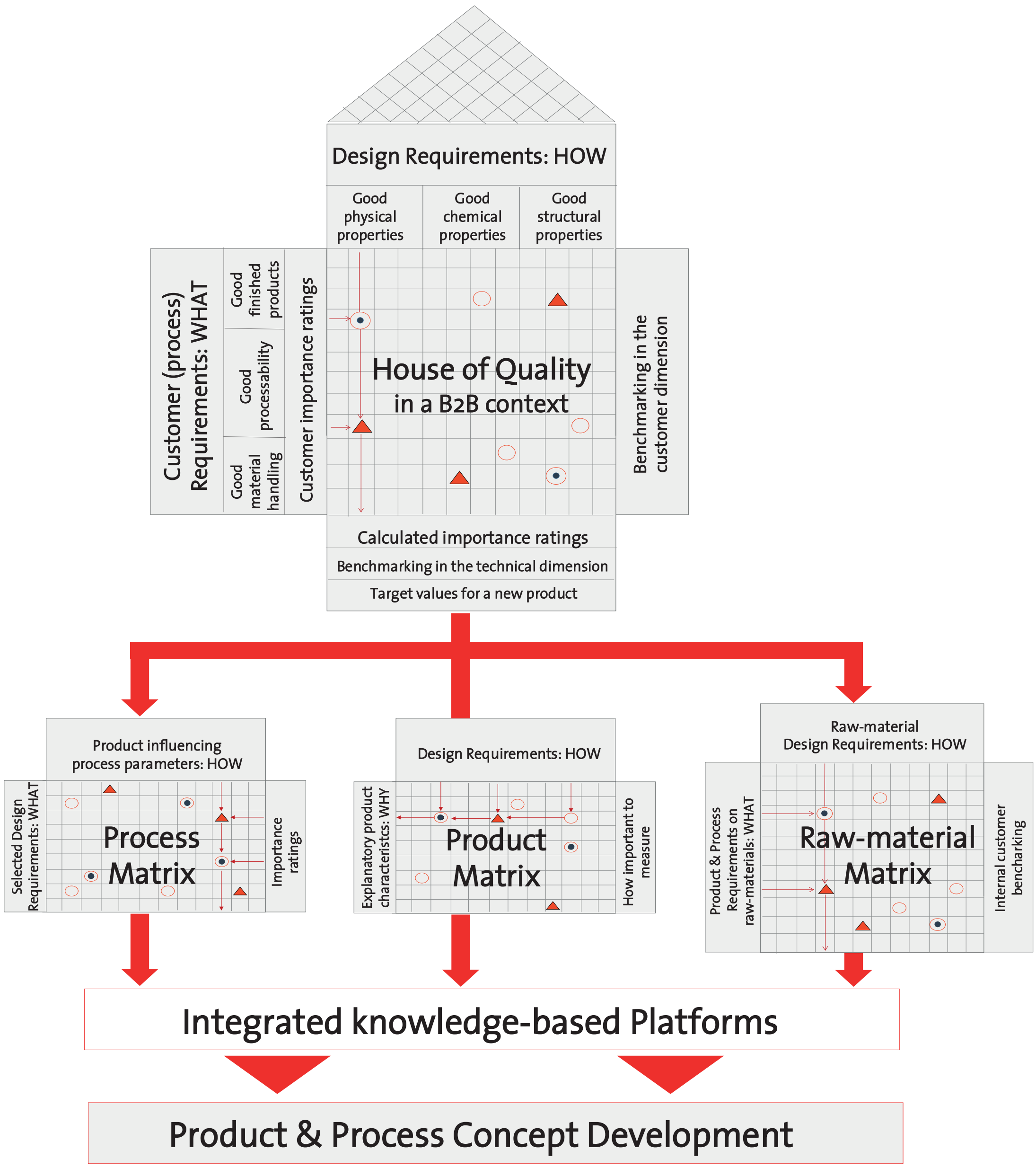
2.4 The House of Quality

In product development, when customer requirements are to be translated into design requirements, each requirement in one of these dimensions often relates to multiple requirements in the other dimension. This problem was solved with the basic QFD methodological matrix approach of positioning the design requirements at a right angle to the customer requirements and thereby defining a relationship matrix in which every possible relationship could be identified and assessed (Day, 1993). Because of its house-like shape, the matrix was later denominated as the "House of Quality" (figure 2). The importance ratings of the hierarchically arranged customer requirements, including a comparison with competing products in the customer dimension (customer benchmarking), are usually collectively called the "Voice of the Customer". When the relationship matrix is used to translate the Voice of the Customer into a technical dimension, those measurable design requirements are further developed, including the direction in which individual product properties need to be improved, as well as a calculation of the individual importance of each design requirement. In the technical dimension, there is now an opportunity to run a technical benchmarking of product properties. After completion of these "rooms", target values for a new or improved product can be set after a matrix analysis.

2.5 The product matrix

In the product matrix presented in figure 3, selected design requirements' HOWs from the

Figure 2 The multiple progression QFD system (mpQFD) adapted to process-industrial use is illustrated. Double rings symbolize a strong relation, single rings a medium-strength relation and triangles a weak relation between different requirement dimensions.



House of Quality are supplemented with new potential design requirements that are further related to inherent product characteristics' WHYs. This matrix, which contains explanatory product characteristics that will answer the question of how product functional properties are created, is "owned" by the R&D organization and will contain both internal and external input, often of an applied research character. When the design requirements in the previously presented House of Quality are reviewed and if there is a need to develop new or more sophisticated measurement methods and techniques for company internal product development guidance, those complementary HOWs should be included in this matrix. The complementary matrix is utilized either when a completely new product is being developed or if one is seeking an improved understanding of what kinds of deeper underlying mechanisms create the measurable properties of a product. The measurable properties of the final products, and to some extent the necessary process conditions that produce these properties, are often well known by company R&D. However, which inherent product characteristics create those properties, often difficult to measure and sometimes hard to understand, is generally less well known. The more internally and structurally heterogeneous a product is, the greater is the need for this complementary product matrix as a support in the development of new product concepts.

Figure 3 The House of Quality and the product matrix as well as their relation is depicted. Double rings symbolize a strong relation, single rings a medium-strength relation and triangles a weak relation between different requirement dimensions (Lager 2005b). The number of design requirements that can be progressed into the product matrix is limited in order to keep the size of the matrix to a minimum (left bubble). It is often discovered in QFD exercises that metrics for measuring customer requirements are lacking (right bubble).

3 Research approach

3.1 Action research and case study design

Action research can be undertaken by larger organizations or institutions assisted or guided by professional researchers, with the aim of improving their strategies, practices and knowledge of the environment in which they practice. The concept of "action research" was introduced by Lewin (1946) and further promoted by Argyris (2002) as the approach of active involvement combined with expected insights developed through research. Lewin stated that: *"If social scientists truly want to understand certain phenomena, they should try to change them. Creating, not predicting, is the most robust test of validity-actionability"*. A related concept termed "innovation action research", proposed by Kaplan (1998), includes the following phases: observe and document innovative practice; teach, speak, and write articles; and implement the concept in new organizations. A similar concept was later suggested by Birkinshaw et al. (2008). This study project follows an innovation action research approach, involving all authors during seminars and discussions with lead users. The analysis and summary of the project outcomes related to the use of the QFD methodology at the case company LKAB, and finally the publication of this article, must also be considered well in the spirit of Kaplan's proposed innovation action research implementation.

The development of LKAB's next-generation pellet product in collaboration with three lead users (two customers and one equipment supplier to the customers), presented an interesting opportunity for a single case study of co-development in a B2B context. The team of researchers in this study included the three authors of this article with extensive industrial experience in the process industries, inputting first-hand knowledge not only of innovation management but also expertise in using the QFD methodology. There are naturally some disadvantages of doing case studies with prior understanding, but the advantages within a study of this kind can on the other hand be many and they have been well expressed by Markus (1977): *"The problem is how to get beyond the superficial or the merely salient, becoming empirically literate. You can understand little more than your own evolving mental map allows. A naive, indifferent mental map will translate into global, superficial data and interpretations – and usually into self-induced bias as well. You have to be knowledgeable to collect good information."*

An important aspect of case studies is that they often provide rich contextual information that helps the reader to better understand where, when and how the empirical evidence is valid. Since it was not necessary to anonymize the LKAB company, this study fulfilled this ambition well. Moreover, Yin (1994) outlines two requirements for conducting single case studies. A single case should be:

- *A unique case:* Collaboration with suppliers and customers is not unusual in the process industries, however, using customers and equipment suppliers to the customers as lead users in co-development in the process industries has not been reported on previously.
- *A revelatory case that offers a rare opportunity to observe a phenomenon that is normally inaccessible:* The opportunity to obtain first-hand information from the collaboration between a process company and its customers and an equipment supplier in an open atmosphere was a rare opportunity.

3.2 The case company and the development project

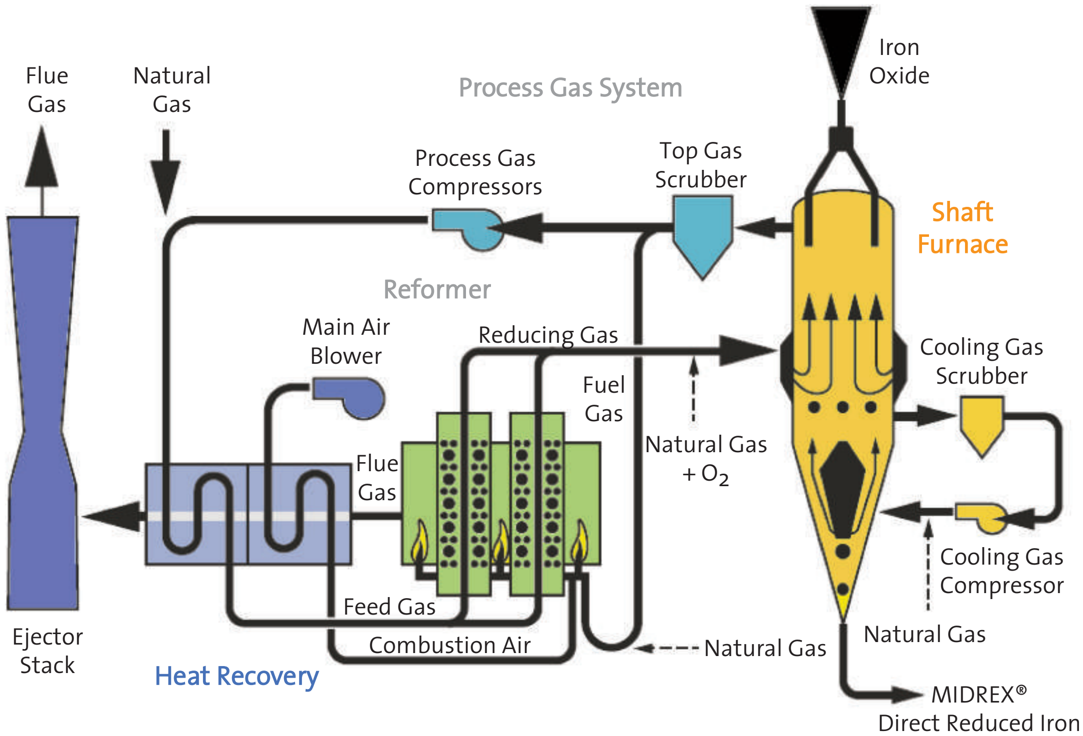
LKAB is a high-tech international minerals group, a world-leading producer of processed iron ore products for steelmaking and a growing supplier of mineral products for other industrial sectors. The company operates six pelletizing plants and in 2014, the company had a turnover close to EUR 2.2 bn. At several production sites in 2014, with around 4,000 employees in the northern part of Sweden, about 26 million tons of products were produced and delivered to LKAB's customers. Pellets for blast furnaces and direct reduction plants account for the major part of the product mix. As a leading pellet innovator, the company has access not only to a recently started high-tech agglomeration laboratory but also to a unique experimental blast furnace (a customer process technology). Application development with its customers is a major concern for the company and "performance in ironmaking" is its promise, which means that LKAB products should provide the best value for customers' processes. To achieve this, it is important to have a continuous dialog with all customers regarding the performance and quality of the pellets. However, to stay ahead of the competition, it is also necessary to understand how future changes in processes, markets and competitors will influence the customer requirements of the product.
Starting with the mining of iron ore, the process chain to produce steel products consists of several complex production stages. After mining, concentration and pelletizing, the finished product is transported by train to a harbor. At the point of loading the product onto the ships, the product changes ownership from LKAB to the customer.

Customers using direct reduction technology are in focus for this product development project. Customers usually produce a rolled product such as rebar, wire rod, sections or coil. The first and most energy-intensive step is the reduction of iron oxide to direct reduced iron (DRI), or sponge iron, as it was originally called. Natural gas is reformed to a mix of CO and H_2 which reacts with oxygen in the iron ore at a temperature of up to 1,000 °C (figure 4). Key factors for the iron ore fed into this process are a high reductive potential, good strength and low tendency for clustering.

Unlike the product from the blast furnace reduction process, this product is solid. Thus, it needs to be melted in the steelmaking process. The steelmaking process uses an electric arc furnace, the DRI is processed to steel with electricity as the main energy source. The liquid steel is further processed in a ladle furnace or vacuum degasser to produce the finished steel composition. The steel is then solidified in a continuous caster to produce billets or slabs. Billets and slabs are afterwards rolled to what is usually the end product at the customer's company, which is distributed to manufacturers of intermediates and further products. In the development of iron ore pellets, it is thus important to consider the entire process chain to the end user.

The aim of the project studied here is to develop a "new generation of pellets" for the direct reduction process. The first step is to build a platform and understand customers' current and future needs. This information, along with new ideas for an improved pellet, will then guide further experimental work. After decades of metallurgical research, LKAB has a large portfolio of possible alternatives for modifying the properties of pellets. However, due to the poor ability of existing test methods to simulate the customer's full-scale process conditions, it is necessary to start with small-scale exploratory laboratory tests, following large-scale laboratory tests, pilot-scale tests and finally full-scale tests at a customer's premises. Compared to

Figure 4 Illustration of the MIDREX® direct reduction production technology. In order to understand the Voice of the Customer in a B2B situation, one must understand the customer's production technology and the demands the process puts on the product (Source: MIDREX®).



companies producing consumer products, LKAB has a limited number of industrial B2B customers, but the process of collecting data for the Voice of the Customer is crucial for the development of the products. However, it is important to select customers that have an interest in the development of both the supplied product and the development of their own production processes and are willing to spend time in co-development. The lead users should therefore ideally be those that will also be involved in the stages of the development of the product and finally as customers for the product. The steel plants usually have few own development resources, so that the best available knowledge of the process and of its future requirements can be found at their technology/equipment supplier. By means of user seminars and regular contact with the clients, such a technology supplier to LKABs customers is able to acquire an excellent base of knowledge not only of the production process but also of the raw materials used in this process.

4 Empirical findings

4.1 Listening to the Voice of the Customer

A development project using the QFD methodology usually starts with listening to the Voice of the Customer by carrying out a number of customer interviews in order to develop a hierarchic structure of individual customer requirements in iterative discussions with the customers. However, previous experiences with using the methodology in the process industries (Lager and Kjell, 2007), as well as the long geographical distance between the customers and LKAB, incentivized the development team to apply a more "lean" approach in drafting the Voice of the Customer. Using LKAB's previous knowledge of customer requirements as a point of departure, those demands were further reviewed with in-house company marketing and R&D expertise in an iterative dialog, gradually refining them into a list of potential customer requirements before the first meetings with the customers. In discussions with the R&D and the marketing function (technical customer support), two lead users were selected and contacted by marketing. Since the customer for a product in a B2B context is the production process through which a supplied product will be processed, it was important that representatives working close to the production process would be present during discussions.

In the first meeting with each lead user, the development project was initially introduced. Afterwards, the QFD methodology was presented and informational material about the methodology was distributed. It was stressed that the intention was initially to focus on the development of the "core product" but that LKAB would later return to the subject of building the Voice of the Customer both on "improved logistics" and "improved application development and services" for the customers. Next, the structured list of customer requirements was presented and discussed in an open dialog, and each customer requirement was then discussed separately and challenged how easy it was to understand. After the interviews with the two customers, the draft list and structure of customer requirements was revised and discussed with the technology/equipment supplier. After the meetings, the revised draft list was sent out to the customers for further comments and improvements.

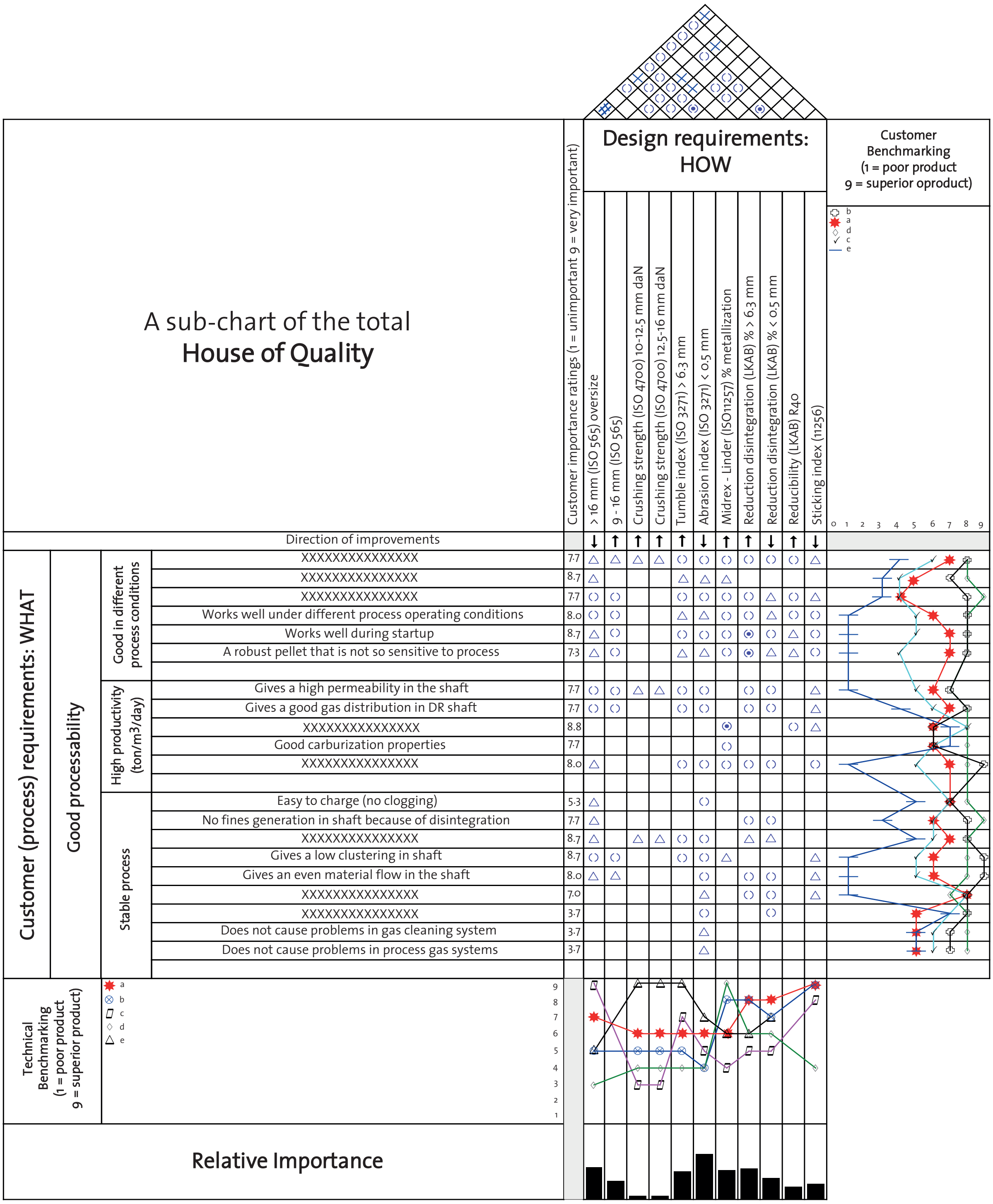
In a second round of meetings with the lead users, each customer was asked to rate the importance of each requirement on a nine-point ordinal scale (1=unimportant; 9= very important). After this rating, they were asked to benchmark LKAB's product properties with competing products in the customer dimension on a nine-point ordinal scale (1=poor product; 9=world-class product). The technology/equipment supplier was asked to rank the three most important customer demands from the perspective of important needs for their future process development and new equipment (figure 5). All lead users were informed that after LKAB had built the House of Quality, they would be contacted for further discussions about individual parts of the relationship matrix. In order to facilitate such contacts, they were offered the necessary software for discussion (IDEACore, 2003).

4.2 Developing a House of Quality

The Voice of the Customer was translated into a technical dimension in the House of Quality (figure 5). This task, which was performed internally at LKAB, involved the company's senior expertise in product development. An example of the dynamics of the matrices is as follows: the customer requirement "works well during startup" has no relation to the requirement "crushing strength" (of a pellet) but has a medium-strength relation to the design requirements "tumble index" and "abrasion index". The technical data are the results from laboratory testing on LKAB products and on competitors' products. The roof of the House of Quality is often called the correlation roof. Since products from the process industries are more or less homogenous, changing the intensity of one design requirement will often have a corresponding effect on another design requirement.

This is complicating product development in the process industries which makes the correlation

Figure 5 A selected part (sub-chart) of the House of Quality. In the room “direction for improvements” (IDEACore, 2003), an upward-pointing arrow represents a desire for improving a design requirement, while a downward-pointing arrow represents a desire to diminish the design requirement. Double rings symbolize a strong relation, single rings a medium-strength relation and triangles a weak relation between different requirement dimensions. In the roof, crosses symbolize design requirements that are hostile to each other, while rings represent design requirements that are friendly to each other. The censored parts (XXX) represent customer requirements that are confidential.



room rather important. This can also been seen in the roof of figure 5. Since the relation between the design requirements "tumble index" and "abrasion index" is strongly positive, an improvement of the "tumble index" will automatically show a decrease in the "abrasion index", which is very positive since the disintegration of pellets is not wanted.

On the other hand, when the design requirement ">16mm" increases, the fraction between "9-16mm" decreases, which is strongly negative since that fraction is the preferred one. The relationship matrix was afterwards used to calculate the importance ratings in the technical dimension, using the importance ratings of the individual customer requirements. As we can see here, a well-designed House of Quality built on a solid ground of the Voice of the Customer is a tool for setting interactive product specifications for new products or improvements.

4.3 Developing the product matrix

In order to create the product matrix, brainstorming sessions regarding features creating the functionality in a pellet were held with LKAB's experts on pelletizing and product development. These features were then classified and organized in a structured list, which is denominated as the WHYs in the matrix (figure 6). In the House of Quality, the measurements for the design requirements are mainly internationally recognized standard test methods and some of them are discussed with the customers. However, since these test methods sometimes do not correlate well with how well the product behaves in the customers' processes, one objective with the product matrix was to examine potentially better test methods in order to develop an improved product. Thus, the product matrix is a tool not only for relating design requirements' HOWs to exploratory product characteristics' WHYs but also, and more importantly, for guiding the development of better test methods.

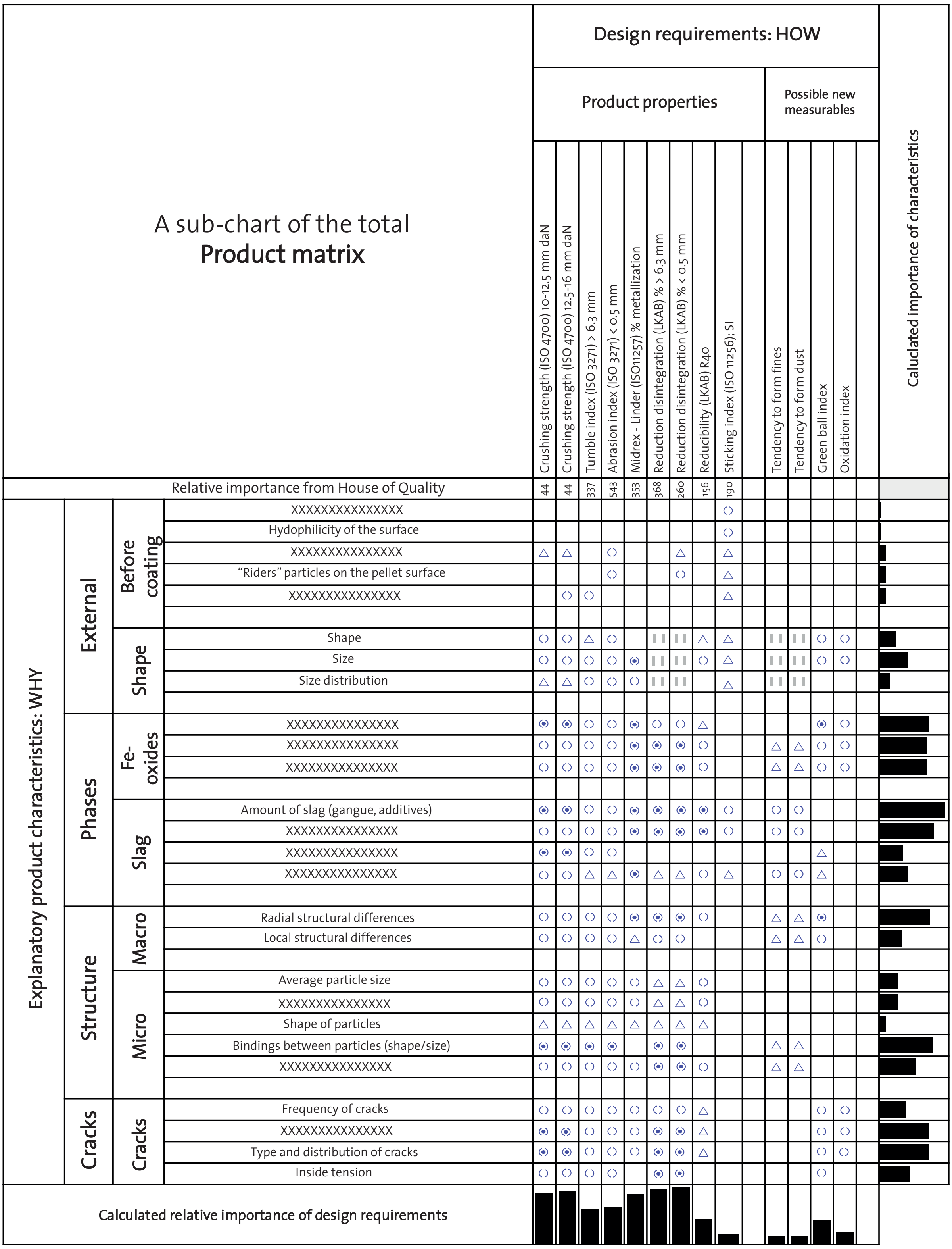
For example, from the House of Quality it can be seen that the customer requirement "works well during startup" has been given a weight of 8.7, so it is considered to be very important. It has also a medium-strength relation to the design requirement "abrasion index" as well as a strong relation to the design requirement "reduction disintegration (LKAB) % > 6.3" that is considered to be of great importance for the other customer requirements due to its high relative importance. These design requirements are progressed into the product matrix, where they are strongly related to, for instance, the explanatory product characteristic "bindings between particles", implying that such bindings are needed to be controlled in order to create pellets with the design requirements low "abrasion index" and high "reduction disintegration (LKAB) % > 6.3" and hence, to be in line with the customer requirement, "works well during start-up".

4.4 Some general experiences and future activities

Since only two customers and one supplier were selected as lead users, the validated Voice of the Customer will be used in future contacts with all customers, preferably in connection with normal contact meetings but likely in some cases also as a mailed survey. The House of Quality will be further used during the following development phase in interaction and discussions with customers. These will not be discussions of the full House of Quality but rather of cut-out pieces (sub-charts) of the matrix selected in order to develop a greater consensus on how the design requirements relate to customer (process) requirements. One shortcoming in co-development with lead users selected from a company's existing customers and users of the company's existing products is that they often, and rightly, focus on existing production processes, today's product properties, and their related advantages and disadvantages of these. For this reason, one equipment supplier was selected and accepted for involvement as a lead user.

The development of the product matrix proved to be a long and iterative journey of learning. Since the product characteristics' WHYs had never been collected and systematically structured, the development of this part of the matrix took considerable time and effort by the R&D organization. During consecutive meetings, different internal experts and specialists became engaged, and this continued throughout the development of the relational matrix. The matrix proved to develop into a very interesting instrument for organizational learning and a collection of tacit LKAB knowledge that already existed (de Brentani and Reid, 2012; Polanyi, 1983) to some extent in the R&D organization. The product matrix will be further developed and will be in a constant state of flux during the whole development cycle. As one researcher pointed out, this matrix will provide a platform for the development of "conceptual explanatory models" that describe how product functionalities are related to more or less measurable product-inherent characteristics.

Figure 6 A selected part (sub-chart) of the product matrix (IDEACore, 2003). Areas with grey lines in the matrix represent relations of high uncertainty.



5 Discussion and managerial implications

The usability of the QFD methodology as a product development tool has been generally acknowledged (Griffin, 1992; Griffin and Hauser, 1993; Lager, 2005a; Miguel, 2013), not only as a solitary methodology but also as a part of other methodological approaches like TQM and Design for Six Sigma (Tennant, 2002). Returning to research question 1, the usability of the QFD methodology as a facilitating tool has only been studied in the pre-development stage of a product development project in this case study. As such, this methodology has proven to be a useful tool in the dialog with B2B customers. However, the development team is inclined to believe that the deployment of the methodology could be expanded further, and will actively pursue its use in the following development stage. It is thus presumed that QFD can also be further deployed in post-product development activities, including the marketing of future improved or new products.

Backman et al. (2007) show that the formal processes designed to deal with product concepts at the front end are insufficient, especially in terms of market and customer-driven concepts. In this study, it is argued that the formal work processes for product development at the front end are also not well adapted to delineate production-driven requirements. In the process industries, where the products are intimately connected to the production process (Frishammar et al., 2012; Lager et al., 2013; Rousselle, 2012), it is not sufficient to go from pre-development to product development based on a single product concept. In order to develop products that also are designed for "manufacturability" (Boothroyd et al., 1994), it is proposed that the product concept will need a complementary process concept. Such a process concept then defines what production capabilities are needed in order to manufacture the new product defined in the product concept. Depending on the newness (incremental/radical character) of necessary production capabilities, the process concept may only include minor process adjustments or reconfigurations. However, for radically new products, it may sometimes include new production technology requiring substantial capital investments. The conceptualization phase of product development in the process industries should thus involve the development of both a product concept and its related process concept. Such complementary concepts should be well integrated and their conceptualization is likely to be a highly iterative process.

Referring to the multiple progression system presented in figure 2, such new process concepts will probably benefit from the associated development of process and raw material matrices as an "integrated knowledge platform" for further conceptualization. After the completion of the House of Quality and the product matrix, it was thus evident to all project members that one piece of information was still missing. The Voice of the Customer had been translated into design requirements and further progressed into the product matrix and related to inherent product characteristics, but the link to the production process was still lacking. Since the importance of using the process matrix and the raw-material matrix in the mpQFD system is stressed, a future step in this project will be to develop such matrices.

Returning to research question 2, the use of the system in the development of the product matrix proved to be an interesting route to follow. From a management perspective, the usage of these matrices and the creation of an integrated knowledge-based platform contributes to a continuous visualization of knowledge throughout the product and process development. This platform presents an important dynamic capability in order to generate competitive advantage as it reinforces and may even alter and improve the entire knowledge base of the company.

Different sectors of the process industry share a large number of characteristics related to their production systems and their innovation environment, but those characteristics significantly differ from other manufacturing industries. The consequence is that results from researching innovation in other manufacturing industries are of less interest to the process industries, while research aiming at the process-industrial cluster of industries are likely to be most interesting to, if not all, but for many sectors of the process industries. In one previous workshop related to innovation in a process-industrial context, it was thus concluded that: *"It is not to be said that prior research into management of R&D and innovation in general does not apply to the process industries, but rather that research results from other domains may very well be useful for the family of process industries as well. However, the idiosyncrasies of process firms are likely to influence the conduct of R&D and innovation and call for improved methods, tools and an actionable and improved knowledge base for R&D management and innovation."* (Lager et al., 2013).

In this perspective, it is argued that the research results of using the Quality Function Deployment methodology adapted for process-industrial use (mpQFD) in this case study could be applied in many different sectors of the process industry. Since products e.g. from the chemical industry are often supplied in a B2B context to other process sectors like the minerals & metals, pulp & paper and food &

beverage industries, using industrial lead users should be an interesting avenue to follow.

6 Conclusions and further research

The usability of the QFD methodology for the co-development with lead users can be confirmed with regard to the iterative development of the Voice of the Customer. Discussions flowed well during the meetings in different cultural settings and the otherwise common discussions of a single product specification and "the problem of the day" were avoided. The outcomes from the discussions and the tangible information related to the customers' use of the product in their production processes can be expressed as an improved customer understanding. The initial idea to engage a technology/equipment supplier to the customers as a lead user proved to be a sound development approach. Involving the customers' technology/equipment supplier as a lead user in B2B product development, is thus one general recommendation and contribution of this study, which is in line with previous experiences (Aylen, 2010; Lager and Rennard, 2014). So far, the methodology has only been used in the pre-development part, but the lead users will afterwards also be involved in the development phase.

The overall impression of those involved in this project and the general conclusion of this study is that the QFD system has a strong potential to be deployed as an instrument for knowledge building in product and process development. Selected design requirements, supplemented with new measures, were progressed into a product matrix, where they were related to explanatory inherent product characteristics. This new matrix provided an applied research knowledge platform for improved "product understanding". This is consistent with previous findings indicating that, in order to reap the fruits of this methodology, one must have a long-term perspective (Griffin, 1992; Lager, 2005a), contrary to the arguments advocating a fast "blitz QFD" approach. It was further discovered that this knowledge-building capability of the methodology was closely related to the functionality of the software and its ability to relate and save information to all matrix areas and rooms and even relate information to individual symbols in the matrices. The use of pop-ups displaying this information proved to be very valuable during the working sessions. Absorptive capacity refers to one of a firm's fundamental learning processes – namely, its ability to identify, assimilate and exploit knowledge from the environment – and is crucial for long-term success, since it can reinforce, complement or refocus the knowledge base of a firm (Lane et al., 2001). The systematic use of the matrices and the way the QFD methodology has been used in the pre-development phase – for gathering, valuing and analyzing new knowledge about customer requirements – is believed to contribute to the potential absorptive capacity of the case company. In addition, further usage of the method throughout the development and post-development phases will enhance the transformation and exploration of new knowledge, reinforcing the realized potential capacity (Zahra and George, 2002). Using the QFD methodology as a facilitating tool in the pre-development part of product development in a co-development approach with B2B lead users has proven to be an interesting and important avenue to follow. It is argued that such a development approach could also be used in product development in other process-industrial sectors serving industrial customers in an open innovation perspective.

The often cited disadvantage of the QFD methodology that it is a time- and resource-demanding tool proved to be correct. This was, however, not a serious problem in this project due to its long-term development perspective and the very large amount of other resources that are and will be used in the future, including pilot testing and full-scale trials. However, if the matrices are to be used only in a single event and in a "crash development project", this could be a significant disadvantage. The further use of the QFD methodology in the LKAB project will be an interesting topic for a follow-up longitudinal study, and then in particular the use of the matrices for concept development. The development of well-integrated product and process concepts as a project deliverable before entering the development stage in the product development work process shows promise as an area for future exploration. Finally, the experience of using the QFD methodology not only as a facilitating instrument in contacts with customers but also as a way to enhance absorptive capacity through usage as a general knowledge-building tool and system in company product and process development is another area of interest for further studies.

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