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THE VALUE OF DESIGN INFORMATION IN COLLABORATIVE DESIGN NETWORKS

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ABSTRACT

Collaborative design requires efficient communication, but the value of design information for the collaboration partners is difficult to predict. The dimensions of design information value and challenges related to them need to be identified in order to improve the value of design information for collaboration partners. We analyzed literature in order to understand the value of information in general. We conducted four case studies in four collaborative design networks in order to understand and model the value of design information in this industrial context. The results of our case studies reveal that the challenges of design information exchange in collaborative design networks lie in the capture and reuse of design information, access to information and targeting design information exchange. We found timeliness, relevance, accuracy, credibility, frequency, comprehensibility and accessibility to be important dimensions of design information value. Maximizing information value based on these carefully selected attributes seems to offer us a feasible approach for designing information management processes for collaborative design.

Keywords: design information value, information management, design communication, collaborative design, product lifecycle management

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1 INTRODUCTION

Collaborative design in product development networks creates additional requirements for design information management compared to company-internal design. In collaborative design projects, the delegation of tasks between the companies changes as all the tasks are not known in the beginning. Therefore, it is impossible to cover every situation in contracts. As the design, manufacturing, testing, and maintenance of a product are conducted in different companies, also the knowledge of these processes resides in respective companies. Changes to product specifications might affect any of these network members, and should thus be efficiently communicated to them. The engineers who work in different locations use different systems and computer platforms. They have to be able to view parts designed by other team members, design assigned components or sub-assemblies under constraints specified, analyze, discuss and modify design solutions, propagate design modifications as soon as possible, and review and verify design solutions in different phases of a development process (Domazet et al. 2000). Appropriate communication support tools are important, and many design teams miss interfaces because project planners have not thought through their use of communication tools and shared platforms (Sosa et al. 2007).

Documents and their consistency, usage, proper storage and linking are a source for improvement when business processes are developed, because many of the problems in business processes are related to information sharing and exploitation (Eloranta et al. 2001). Electronic data exchange is used in product development networks to coordinate tasks and to share information of task execution. This information includes task descriptions and information of task changes and completions. Such information is of high value to the network members. However, the timing and contents of the information exchanges are extremely important. Errors and deficiencies in information quality, as well as delays in the exchange cause unnecessary rework. Furthermore, information that is sent too often and to too many recipients causes information overload for the recipients and can at worst paralyze their operations. In addition, the confidentiality of design information requires efficient targeting of the exchange. There is a need to model the value of design information on the network level to enable the exchange of valuable information between the network members.

The value of information comes from avoiding unnecessary rework and delays in the schedule, as well as from diminishing the costs of the data exchange and data handling. We will identify the challenges that diminish information value in collaborative design in four case studies in collaborative design networks. These challenges will then be categorized according to different attributes of information value in order to find out the most challenging areas. The main contribution of this study is a definition of information value in the context of collaborative design. It is based on previous research of information value and adds to it by concentrating on a specific application environment. This definition can be used in the development of design information management. With an emphasis on the most challenging information value attributes, processes can be improved in a way that increases the value of design information. Such improvements should diminish the costs of rework and scrap due to working with outdated information, diminish the costs of searching for updated information, make design information available for the whole network and thus create a new source of organizational knowledge, and diminish the burden of information overload.

2 INFORMATION VALUE

Information value has been analyzed in decision analysis (Howard 1966) and information economics (Hilton 1981). Howard's (1966) information value theory describes the importance of uncertainty to a decision maker by illustrating the economic impact of uncertainty. With this theory, it is possible to assign a numerical value to the elimination or reduction of uncertainty in decision making. Information economics is based on statistical and economic decision theory and it models the selection of an optimal information system (Hilton 1981). Hilton (1981) has identified four determinants of information value: (1) the decision maker's flexibility, (2) the decision maker's technology and environment, and his relative preference for the outcomes, (3) the decision maker's uncertainty regarding the technology or environment, and (4) the nature of the information system. He concludes that only certain characteristics of the information system have a consistent directional effect on information value, whereas the other determinants – although having a significant effect on information value – do not have a consistent effect across decision makers and decision settings.

Information value depends thus on the context of its use; the same piece of information can be extremely valuable in one context, but be totally useless – or even an obstacle – in another context. Birchler and Bütler (2007) define information value as "the increase in utility from receiving the information and from optimally reacting to it". Glazer (1993) lists three general components of information value: information can make the revenues of subsequent transactions greater or the costs of subsequent transactions lower than they otherwise would be, or the information itself could be marketed and sold to other firms. As the use of a piece of information changes, its value changes according to the new context, even if the intrinsic quality of the information stays the same. Emergent uses for information can thus dramatically increase its value.

According to Denning (2006), valued information at the right time is "not so much about technology as it is about deciding which information is of value and to whom, and then configuring the technology accordingly". Su and Jin (2004) give a definition of information value to the knowledge worker: "V = intrinsic value * (accuracy + timeliness), where intrinsic value is the actual value that a customer has applied and the potential value that cannot be utilized by the customer". Ahituv (1989) includes the cost of providing the information as an attribute of its value.

Epstein and King (1981) have taken a multidimensional attribute approach to assessing the value of information. Also Ahituv (1989) suggests that various attributes constitute information value and that these attributes have different emphasis in different process contexts. This approach has similarities to approaches for assessing data quality as a multi-dimensional concept (Pipino et al. 2002). "Data quality" is defined as "data that are fit for use by data consumers" by Wang and Strong (1996). They include value-added as an attribute of data quality, which makes the terms information value and data quality rather overlapping. Therefore, we have included data quality studies in the following literature review. The cost of information quality affects the enterprise performance in two ways: the direct cost as a result of "information scrap and rework", and the missed and lost opportunity due to poor perceived information quality (Su and Jin 2004). Su and Jin (2004) include cost and profit in data quality attributes, whereas Epstein and King (1982) talk about cost-efficiency.

In the following sub-sections, we will introduce attributes of information value and data quality from previous literature.

2.1 Timeliness

Information should be available at the right time in an up-to-date status. Timeliness has been recognized as an important characteristic of information by numerous researchers (Ahituv 1989, Korhonen et al. 1998, Maltz 2000, Su and Jin 2004, Wang and Strong 1996, Zmud, 1978). Maltz (2000) defines timeliness as "the degree to which information is perceived as current and actionable". Epstein and King (1982) use the term reporting-cycle. As a component of information value, the timeliness factor reflects the frequency of information exchange and that the information is up-to-date (Ahituv 1989).

2.2 Relevance

If the information is not related to the receiver's work, it only causes confusion and wastes time. Relevance has been mentioned by several researchers (Ahituv 1989, Epstein and King 1982, Korhonen et al. 1998, Maltz 2000, Wang and Strong 1996, Zmud, 1978). Maltz (2000) defines relevance as "the appropriateness for the user's task or application" and suggests that random e-mail is a prime contributor to information overload.

2.3 Accuracy

Information exchanged with other companies should be correct and complete. Accuracy (Ahituv 1989, Korhonen et al. 1998, Su and Jin 2004, Zmud, 1978) and completeness (Wang and Strong 1996) or sufficiency (Epstein and King 1982) are closely related attributes, because partial information can be considered inaccurate, even if correct.

2.4 Credibility

Maltz (2000) defines credibility as "the degree to which information is perceived by the receiver as a reliable reflection of the truth". Wang and Strong (1996) include believability, reputation, and objectivity in their intrinsic data quality attributes. Korhonen et al. (1998) talk about validity, whereas Zmud (1978) and Epstein and King (1982) use the term reliability.

2.5 Frequency

Frequency of communication increases its perceived information quality to a point. Infrequent information is more likely to be ignored, because the receiver has not learned how to interpret the information (Maltz 2000). Korhonen et al. (1998) included continuous flow in their list of information quality attributes. Sosa et al. (2002) found that the relative location of interacting team members influences both communication frequency and media choice: communication frequency tends to decrease with distance, independent of the media used to communicate.

2.6 Comprehensibility

Maltz (2000) defines comprehensibility as “the perceived clarity of the information received”. This term is also used by Wang and Strong (1996), who additionally list interpretability, ease of understanding, representational consistency and concise representation as representational data quality attributes that can be seen as related to comprehensibility. Epstein and King (1982) use the term understandability; Korhonen et al. (1998) talk about intelligibility; and Ahituv (1989) lists format as an attribute of information value: the recipient has to be able to view the contents easily.

2.7 Accessibility

Korhonen et al. (1998) include accessibility and visibility in information quality attributes. Wang and Strong (1996) talk about accessibility and access security.

2.8 Other attributes

In addition to the information value and quality attributes described above, there were other attributes mentioned in different studies. Wang and Strong (1996) mention appropriate amount of data among the attributes of contextual data quality. Maltz (2000) refers to richness as the possibility to get instantaneous feedback to interpret the information being communicated, which is high in face-to-face communication and low in written information. Epstein and King (1982) have freedom-from-bias, comparability and quantitativeness on their list of attributes.

3 MATERIAL AND METHODS

We chose a theory-creating approach for our exploratory study. We conducted four case studies (Yin, 1994) about design information exchange in four company networks. All networks had global operations. Three of them were developing and producing consumer goods and one was developing and producing investments goods. From the first network, we included the brand owner, a metal parts supplier, and an electronics supplier in our study. From the second network, we were able to study the main supplier only. From the third network there were the main supplier and a design supplier, and from the fourth network the brand owner and a design supplier.

Our interviews were conducted in Finland, Austria and Germany. Multiple investigators were used to foster divergent perspectives and strengthen grounding, as instructed by Eisenhardt (1989). We used semi-structured interviews to discuss the current state of the processes, methods, tools and systems from the viewpoints of collaborative design, engineering change management (ECM), design data exchange, and information technology (IT) support for them. We interviewed 76 persons: designers, engineering change managers, material leaders, project managers, outsourcing business developers, Product Data Management (PDM) system specialists, and system integration specialists. In addition to the interviews, we received various documents from the companies, including process guidelines, bills of material (BOM), engineering change documents and drawings. The interviews were recorded and notes were taken during the interviews. The recordings were transcribed and added to a research database.

To identify the attributes of information value that are most important in the collaborative design context, the interviews were analyzed with information value attributes identified in the literature review as keywords. The data was analyzed with Atlas.ti software by coding it with these keywords to achieve a unified and reusable research database. We used an iterative approach for data collection, coding, and analysis, as recommended by Eisenhardt (1989).

Emergent themes were categorized and patterns and connections between the themes identified. Within-case analysis included writing a detailed case report for each case company. These reports were intended for the companies' internal use, but also served in the generation of insight (Eisenhardt, 1989). Furthermore, the analysis of each case study was presented to the people we interviewed to make sure we had understood everything correctly. In cross-case analysis, we identified common challenges in the case companies. The common challenges were presented to case company representatives in a common workshop, where the challenges were discussed.

4 RESULTS

In the following, the results from the interviews are presented according to the information value attributes.

4.1 Timeliness

The information available for the supplier was not always up to date. Sometimes the customer informed the manufacturing supplier about a change days after the changed parts had arrived from component suppliers to the manufacturer. It had also happened that a component supplier informed the manufacturer about an engineering change, but the manufacturer did not have a contract for the new component code. This was solved by reporting it as an old component, and then manually correcting the lists of used components when the official information was received from the customer. A delayed engineering change notification (ECN) has resulted in treating two different component versions as the same, because the incoming goods personnel just put all in the same shelf and the boxes with the version information were thrown away.

Version management was found to be problematic in the company networks. The master documentation was typically stored in the customer's systems and the suppliers had copies of the drawings in their own databases. There were no notification mechanisms to the other party if the other was modifying the documents. New versions of documents were not always communicated to suppliers. In one case, after manufacturing the product for a year the customer asked which version was used, and only then it was noticed that no-one had communicated the change to the supplier.

The speed of design information exchange was important. Some information needed to be sent to other partners immediately, whereas some could wait and be transferred in batches. The design information exchange between the customer and the supplier required considerable amount of laborious, time-consuming, and error-prone human interaction, which slowed down the process. Furthermore, the data-transfer systems used in the case companies were rather slow; it took about 4-5 hours to transfer large files in one network, and about an hour to transfer one 3D model in another network.

4.2 Relevance

If the supplier needed a specification, they had to ask for it, or initiate a file transfer. Naturally, this required that they knew about the specification and that they knew they needed it. Needed specifications were not automatically sent to the supplier. This was especially problematic when the project used components that were owned by another project. The owner could change the data and if the owner did not know who all used the data then information about the change was not communicated to everyone.

Some systems included a mailer functionality that should have sent information about changes to relevant stakeholders. For example, at one company the product managers should have received a notification every morning if there were engineering change requests (ECR) for them in the system. There had been problems with this functionality, however, and information about new ECRs was sent manually instead. Another case company had a totally opposite problem: they received a mailer notification every morning with tens of changes. At worst, there had been 130 attachments to a mailer message. The supplier did not have the resources to search for relevant information from such messages, so the customer's product managers sent relevant ECRs to them by e-mail.

Engineering change analysis was seen problematic from time to time at one customer. There was a list of accounts for ECN approvals. Sometimes the lists themselves were subject to changes, but the product managers were not notified of this and the old approvers did not approve or demote ECNs anymore. Furthermore, the ECN time was delayed as a consequence of vacation, sick time, holiday, business trips, etc. despite a deputy function in PDM. It was stated that many persons simply do not open the PDM system with the ECM workflow to see what their pending issues are.

4.3 Accuracy

Sometimes changes were not documented; for example, if engineers were talking with each other and there was no drawing:

"In 10-20% of the cases when we check component validity we have to wonder if all the changes in the drawings have been implemented or if the changes in the component have been documented"

There were also mistakes in manual data input when transferring data from a spreadsheet to the PDM system. If this happened, the part or object name was never be found. Also, if the customer made a typo while sending a code to the supplier, the customer could receive 20 drawings with wrong codes that had to be changed again. In one network, drawing changes were sometimes sent without change identifiers and such changes could not be used. Sometimes files were received without any additional information, and many people had to be asked to find the correct project.

There were several challenges with component codes. In one network, component documentation could be changed but the component code remained the same. Creating new codes was considered expensive, and people wanted to avoid it even when doing so resulted in having two different components with the same code. In another network, the situation was the opposite: there was no definition of the data needed by different stakeholders, no naming conventions and varying versioning policies. This resulted in multiple codes for a component, limiting the possibilities of component consolidation for placing larger orders and gaining on the economy of scale.

4.4 Credibility

In one network, low trust was found to affect many processes and brought challenges for coordination. Over the time trust had, however, been built slowly. Contact networks built by the customer's engineers working at one supplier's premises and vice versa were a very valuable means of direct communication and served for trust building. These unofficial communication channels were seen very effective in information transfer between the customer and the supplier. However, all the information was not documented and inserted to relevant information systems. An example regarding assembly instructions resulted from the customer's engineers directly informing production of what to do, but failing to update the documentation and thus creating a state of confusion in production.

In another network, the information was flowing from many channels, and the supplier's employees needed to clarify contradictory information coming from the customer. In one network, preliminary information about upcoming changes was not given in much detail to the suppliers by the product managers. Nevertheless, there was personal trust between the technical personnel, so some information was shared unofficially:

"For me it is person related, we trust the technical guys and they trust us. But with a salesperson, one never knows, they have their political things… On the technical level [the trust] is nearly 100 per cent."

4.5 Frequency

On average, every component was changed 5-10 times in one case program, based on released changes. There were about 600 changes to the costed BOM during the program. Most of the engineering changes happened in the beginning of the program. Changes were made every day, but they were piled up so that after the builds there were always many changes. In another network, it was estimated that for 17 suppliers and all current products in Europe there were about 300 change-related events a month. At the beginning of a product lifecycle, there could be as much as 10 ECNs a week, but the amount decreased towards the end of the product lifecycle.

In another network, 3D data was transferred in batches from the supplier to the customer, because the data transfer was laborious for the customer. It was only done at certain stages, not continuously. Changes were not bound to build plans; the builds come no matter what and changes keep coming:

"In one project, whose products are on the market already, we are still making some changes, because some drawings or parts are still changed."

4.6 Comprehensibility

The most obvious issue regarding comprehensibility is when two parties do not speak the same language. One Finnish supplier had a customer from Germany, and the customer's IT systems and a large part of all documentation was in German. Communication between the customer and the supplier was handled both in English and in German. As the supplier's personnel spoke Finnish as their native language, this resulted in numerous cases with no common language. This made communication slow, simplified and ineffective. In another network, the different parties spoke the same language, but changes were documented in group-specific slang which was difficult to understand for outsiders.

The biggest problem appeared to be insufficient information related to engineering changes. That is, the customer sent ECRs and notifications with too little, incomplete of conflicting information. This required separate inquiries before the change could be further processed.

"The worst case was when the only information about a change was „to be changed", no description of what to change or how."

Naming conventions varied from company to company and caused confusion:

"We don't know about the relations of words version and revision and their impact on component interchangeability."

4.7 Accessibility

Access rights to partner's systems have to be considered well. Two extremes were seen with access-rights policies: deny access to everything and have the partner request access rights separately for each piece of information, or give access rights to everything and monitor what data is accessed by the partner. If the information is not available in the systems or if it is in a format that cannot be viewed by the partner, even carefully thought of access rights policies cannot give access to the information.

Another accessibility challenge is having all change-related discussions stay in the employees' mailboxes instead of copying the discussion to the PDM or ECM system. Such copying rarely happened, and the systems were not considered very efficient for change-related discussions. Therefore, all decision information was dispersed over mailboxes of several people.

Software incompatibilities caused a lot of work. Using different CAD systems meant that if the customer wanted to look at a part, they had to ask the supplier to create a pdf file of it or ask the supplier to show the needed files when visiting the customer. One supplier had purchased 10 expensive viewer licenses for their customer's CAD system. As an estimated 10-20% of the changes (100 000 in total) needed to be clarified using a colleague's 3D viewer, this was not considered a good practice. Disturbing a colleague who had the viewer license was considered uncomfortable.

Further accessibility issues were caused by system usability. One supplier used the customer's product structure system. The system used codes that could be found from code manuals. Although the users usually remembered the codes they needed, there were weekly difficulties with the codes. Learning to use the systems could take up to 6 months. During this time a new designer was not very productive.

"It's a generation thing: the new dynamic CAD people do not want to update the old system with an old fashioned DOS-like user interface. This is a big problem; it is the core of the product structure. They just update the [PDM] system, draw fancy pictures in there and forget about the [ECN] to [the product structure system]."

In one company, there was a software client offered for PDM system access, but it was considered too difficult to use, and people preferred to use a web interface instead. If something was not possible to do with the web interface, the interviewees sent an e-mail request to the IT department. There was also a problem related with targeting the information to correct people in this PDM system, as adding affected documents to an ECR could take up to two hours. In another network, it was stated to be easier to call or visit someone and look at the drawings, than to use the ECM system. In one case network, a separate Excel file was used for making searches from reserved code numbers for each product development project. Using the PDM system was considered more laborious than the double work of updating the Excel file and the PDM system.

Some information was still distributed on paper only. In one network the cost impact of a change was retrieved from the customer's ECM system and distributed on paper with the drawings. In another network, old paper-format documentation was sometimes scanned and put to the PDM system. Nevertheless, the metadata was not filled in, and that meant that it was not possible to use search functions. There was no possibility to find in which product a component was used. In addition, the changes might not have been scanned, so there was no way to tell whether the information was correct. Often the documentation was so poor or residing tacitly in the heads of the employees, that production could not be transferred to a better supplier.

4.9 Summary

There were several challenges with information value in our case networks. A total of 294 quotes were categorized with keyword *problems*. In 46 of these quotes the problem was either not related to information value, or it was a repetition of a previously mentioned challenge. The remaining 248 problem quotes were classified according to the information value attribute in question. Some of the quotes included more than one challenge. The only information value attribute that was not found problematic was frequency: the frequency of information exchange varied according to project phase, but this was seen as the nature of product development projects. The challenges and the information value attribute they are related with are listed in Table 1. The table also gives the amount of times a challenge related with the information value attribute was mentioned in the interviews.

Table 1. Summary of challenges categorized by information value attributes

Attribute of information value	Challenges found in the case studies	Number of challenges mentioned
Timeliness	- Information received too late (or too early) - Document ownership and version control - The speed of design data exchange	47
Relevance	- Not knowing who needs to be informed - Automatic notifications not working - Wrong people in engineering change analysis loops	24
Accuracy	- Differences between drawing and physical product - Inaccurate component codes: same components with different codes and same codes for different component versions	52
Credibility	- Trust building takes time - Many sources of information	11
Frequency		0
Comprehensibility	- Language - Missing or ambiguous metadata - Different naming conventions	29
Accessibility	- No access or only limited access to partner's systems - Information dispersed over mailboxes - Different software or software versions used - System usability - Old paper-format documentation	65

5 DISCUSSION

5.1 Scientific contribution

Our main contribution to the literature on information value is the network aspect and how it affects information value. We found timeliness, relevance, and accuracy as the most acknowledged information quality and value attributes in previous studies. These attributes also proved to be important in our cases. However, the most challenging attribute in our cases was accessibility, which was only mentioned by Korhonen et al. (1998) and Wang and Strong (1996). We believe that the networked way of working shows especially well in this attribute, as a lot of data is stored in the IT systems of another company and thus access to this data can be difficult to obtain. Furthermore, comprehensibility-related challenges were mentioned more often than relevance related. This could also be a result of the networked way of working: engineers in different companies use different jargon and partners from other countries might even use a different language. This supports Ahituv's (1989) statement that the emphasis of different attributes varies according to process contexts.

5.2 Managerial implications

Our results show that the accessibility and comprehensibility of information are important in collaborative design networks. Consequently, these attributes need special attention when designing processes and their IT support for inter-company collaboration. System access has to be designed in a way that guarantees access to relevant documents when needed. Slow procedures for demanding access separately for each piece of information are not acceptable in this context. Furthermore, the comprehensibility of information requires common agreements of the language and vocabulary used.

As we take the value of information as the starting point, we need to consider the huge network of transactions resulting from the collection, handling, and exchange of information. The question is how the value of information is distributed in the network. Each network member should benefit from information processing more than the effort they put into it. If other work tasks appear more rewarding, information processing tasks might be overlooked. Another issue is the difference in the value of information for its sender and receiver. For example, e-mail is typically of high priority to its sender, but not necessarily so to its receiver.

5.3 Evaluation of the study

To achieve construct validity, we used multiple sources of evidence: interviews were supplemented with related documents and we studied the information systems used. To establish a chain of evidence, the interviews were transcribed and coded with relevant keywords. We wrote a separate case study report for each company network. Drafts of these reports were sent to the key informants in each company, and the reports were revised according to their comments. Furthermore, results from each case study were presented to a group of informants in each company to assure correct understanding.

To build internal validity, evidence was searched for “why” behind relationships (Eisenhardt, 1989). This was achieved with pattern matching across cases and by identifying causal links and thus building explanations. We predicted a pattern of challenges in design information exchange prior to data collection. This pattern was then compared with the empirical patterns identified in the cases. Internal validity of the study was enhanced as the patterns coincided.

We used a case study protocol to enhance the reliability of our study, as proposed by Yin (1994). Furthermore, a case study database was used for entering interview transcripts, and other research material. The flexible and opportunistic data collection methods, such as the semi-structured interviews, allowed the researchers to take advantage of emergent themes and unique case features.

5.4 Limitations of the study

Due to the case study method the direct generalizability of our findings is limited to the case context. Furthermore, the external validity of our research is related with the geographical location of the case companies, our focus on certain network members, and the financial support of the case companies. The case networks were European, with a strong emphasis on Finland. However, many interviews also included comparisons to working with Chinese partners, and challenges with these partners were similar. We have focused mainly on the main two partners: the customer (a brand owner) and the supplier (an engineering design supplier or an original design manufacturer). Those two partners usually represent the majority of the interaction within the network. We did not examine all stakeholders of the product development networks. In one case, we were only able to study the collaboration from the supplier’s side. In addition, each case network included one company that partially funded the research. Assumingly, the companies willing to pay to participate in the research experience such challenges that they are willing to invest in a research project. Therefore, companies that do not experience challenges in this context were not included in the study.

6 CONCLUSIONS AND FUTURE WORK

The value of information comes from using the information to avoid extra costs. With the right information at the right time efforts can be directed to productive work and unnecessary rework can be avoided, thus avoiding delays to the schedule. Furthermore, the handling and exchange of information add to costs. Unnecessary work in information handling should also be avoided. Information handling costs include the human limits to information processing: how much information can be received and how often without information overload?

We define information value in networked product development as *the costs avoided by having access to comprehensible and relevant information from a credible source on time.* The value comes from avoiding the costs of using information that is not accessible, not available when needed, incomprehensible, or irrelevant. Because of the turbulent and flexible nature of product development projects, information value to its recipient is hard to predict. However, maximizing information value on the basis of these carefully selected attributes seems to offer us a feasible approach for designing information management processes in collaborative design projects. Using information value as a guideline in designing inter-company data exchange processes can help us to optimize product development processes better on the network level. As one of our interviewees summarized:

"Get rid of the irrelevant information and get relevant information on time, that's the idea."

Future work should find solutions for guaranteeing and measuring the success of design information exchange. This should include mechanisms for evaluating the value of a certain piece of information in order to avoid the exchange of information that is not valuable to the receiver. Furthermore, although our case companies have international operations, it would be beneficial to conduct additional studies in other countries. Further validation in different industries and different countries is needed to help in understanding to what extent the results can be generalized.

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