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ENABLING EFFICIENT COMMUNICATION OF QUALITY DESIGN INFORMATION IN A DESIGN PROCESS

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1. Introduction

Designing and manufacturing products requires the production and distribution of vast amounts of information. Due to the information intensive nature of the design process, poor communication of designer-produced information can lead to mistakes and delays in the process. Designer-produced information is an input to other tasks (e.g., when the bill of materials is sent to the purchasing department). Hence, if the design information is not communicated efficiently, people wait for information to complete their tasks or work with false information.

The aim of the paper is to find ways to ensure efficient communication of quality design information via a communication analysis framework. This framework is based on work done by Maier et al. (2009) and the concepts presented in previous research in this area. The framework is used to classify factors that affect design information quality on four levels to determine how good a quality can be reached. Quality can be understood as the right people having the right information at the right time [Lindau 1995]. Quality design information is designer-produced information (e.g., designs and engineering change (EC) orders) at the right time for the right people in the design process.

First, four case studies were conducted in traditional manufacturing industries to map challenges in the current EC processes. The focus of the first case studies was on communication in the EC processes. Next, three more case studies were conducted in the foundry industry to obtain a deeper understanding of the effects of designer-produced information in supplier companies. Communication between foundries and their customers is important because component design depends on foundries' production process set requirements. When designing casting components, the production set requirements for the design need to be taken into account, e.g., material feed and wall thickness. In addition, specific dimensions and shape accuracy are achieved with tooling, which needs to be taken into account during the design phase. [Hölttä et al., 2009] The current communication and collaboration policies were studied.

When comparing the cases where communication challenges occurred to cases with better communication policies, three major factors of efficient quality design information communication can be identified: teamwork, individual awareness and development, and organizational support. These factors represent the three levels used to support information level and efficient communication: the project level, the individual level, and the organizational level. The results indicate that concentrating on these key concepts could help improve the quality of design information.

2. Related research

Collaboration between people in the design process has many benefits, such as reducing mistakes through earlier communication between the supplier and customer [Clark, Fujimoto 1991, Hölttä et al. 2009], or better scheduling performance and flexibility of price-alternatives in partnership relations [D'Amours et al. 1999]. In contrast, the lack of collaboration can lead to rework and wasted time. Traditionally, design and manufacturing activities have taken place sequentially, leading to inefficient and time-consuming iterations between design and manufacturing stages [Shukor and Axinte 2009]. For example, when foundries cast components according to an order with a ready-made design and are expected to provide parts without knowing what they are being used for [Downlatshashi 1997], foundries cannot assist in designing the component. This leads to components that are not easy to cast; therefore, the rejection percentage in production increases.

Maier et al. (2009) assert that reflection on communication is a key factor for successful collaboration. Communication grid sheets are used to assess the current and desired state of communication [Maier et al. 2008]. Maier et al. (2009) present five communication levels in which factors influence communication: organization, project, individual, information, and product. They present areas of influence on each level: organization – organizational structure and culture; project – reflection with the project team and teamwork; individual – personal development and awareness; information – information transmission/handling and availability of information; and product – media of communication, expression of the product, and requirements [Maier et al., 2009].

The work of Maier et al. (2009) highlights three themes that are important in efficient communication: the importance of understanding the collaborators' information needs; the importance of orientation; and the importance of reflection. Collaboration can be supported with IT. Typically, a Computer Supported Cooperative Work tool can assist significantly in the exchange of information between people, teams, and organizations [Monplaisir, 2002]. Information and communication technologies can be applied to improve and promote communication and information sharing in organizations. [Zhang et al., 2004] assert that Web-based product information sharing can be used to support collaboration between design and manufacturing, but a common information repository is not enough. Active coordination of collaboration is needed, e.g., translation of terminology among disciplines [Zhang et al., 2004]. [Shukor and Axinte, 2009] present a manufacturability analysis system to evaluate manufacturing aspects during the design stage, which helps to reduce the costs and time to market of designed products.

3. Method

First, four exploratory and descriptive case studies were conducted in traditional manufacturing industries: two in Finland and two in Sweden. The companies were from heavy machinery, mechatronics, and the automotive industries. The EC process was mapped in each company to get a clear view of the current process and identify all participants. The focus of the first case studies was on the communication in the EC process. Altogether, 57 people were interviewed. People from different functions (product development, purchasing, manufacturing, sales, after sales, and IT support) were interviewed. The interviews were semi-structured, and the questions involved the EC process, challenges in EC management, information flow in the EC process and IT support. The focus of the data gathered for this paper was on finding the challenges related to poor design information quality. Moreover, various product data management and EC management materials provided by the companies were studied.

Next, three case studies were conducted in the foundry industry to identify the effects of the designer-produced information in the supplier companies, and to discover the current information exchange policies. Case studies were done in foundries and in their customer companies. The foundries supply components for the customers. The focus was on suppliers' production. Eleven people (from production, sales, quality assurance, and design) were interviewed in semi-structured interviews. An additional eleven people took part in the discussion during the data collection stage to get a broader picture of the issues. The questions involved communication between the foundry and the customer and their collaboration.

The interviews were recorded, and notes were taken during the interviews. The recordings were transcribed and added to a research database. The data was analyzed with Atlas.ti software by coding it with relevant keywords; challenges, impacts and factors of poor design information quality, and information exchange support of policy. After the interviews, the collected data was analyzed with a communication analysis framework that is based on the work of Maier et al. (2009) to determine why challenges do not occur in some companies and how challenges are solved.

4. Results

In our first case studies the automotive and heavy machinery companies made customized products, which were produced in a 1-5 product series. Customized products meant more designing than with mass production products. Therefore, designers would produce more information, which set challenges for the design process, as compared to refined designs made with time and with mass production as a goal. In customized products, an EC to one component affects all the products in which the component is used. For example, in the heavy machinery case, the EC process started with an EC order, approval of the EC, and EC notification and ended with implementation of the EC. The most common procedure in the case companies was that the purchaser notifies the suppliers of ECs. In the foundry cases, where the production type was mass production, the EC process was the same, but due to mass production, the change would affect a larger number of components. Casting design varied from designing the component together with the foundry to sending a ready-made design to the foundry. Foundries casted small, medium, and large components. The size of the components affects the manufacturing method, e.g., large castings take weeks, but a series of small castings can be done in a day.

4.1 Challenges in Communicating Design Information

In our case studies, where the focus was on EC management, we found communication challenges in companies from the automotive, mechatronics, and heavy machinery industries. The biggest challenges that affected design information quality were the following:

- A lack of awareness of how change affects other parts – When relevant parties are not notified about an EC, this leads to, for example, out-of-date manuals, purchasing ordering redundant parts, and parts not fitting in the assembly. One designer said, “I do not know where the things I do go, and I don’t know the reasoning behind the mailing list I sent my EC orders to.”
- Designers presume others know what they know – When ECs are not documented, this leads to serving the customer with out-of-date-manuals. For example, if the documentation department is not notified of the change regarding delivery of a spare parts book, the user’s manual and machine do not match. “Designers do not document the EC orders accurately because they presume that others know which components and codes the EC order concerns.”
- Roles and responsibilities are not clear – If production or a supplier is not notified of the change, the change is not implemented. “A designer might inform the supplier but no clear roles are defined.”
- Poor usability of product data management system – ECs are not always documented, but instead handled outside the system. Not documenting the changes results in repeating the same mistakes if similar problems occur later on. “There is a possibility to make an EC request first but the system is too heavy; then, we use our own process outside the system to do it.”

The main challenges of poor quality of design information found in foundries were the following:

- Components are not designed for casting – This leads to a lower quality of components and more work because more components need to be cast to obtain the right amount of good quality components. The components may not have enough material or may have too much material for tooling of the component after it has been cast. “Sometimes the machinist complains after he is done that the material was too hard for tooling.”
- Redesign for casting – Components are not designed for casting; thus, changes to the design need to be made for it to be cast. “The casting designer might want to add a material feed when the design is done. This could have been done already in the design phase.”

- The foundry did not know what the component was being used for – Late ECs are needed for the component. For example, the final product might not meet the visual requirements because the foundry did not know which side of the component would be visible in the final product. "It is important to know the product and not just the component, so you can design it right, for example, paying attention to the right details."

Although the challenges listed above were recognized in the small foundry to be common problems in the industry, they did not have these challenges with the three customers interviewed in this case study. The foundry collaborated early with these three customers and had frequent communication throughout the project. Both the customer and the foundry were satisfied with the collaboration; they valued the meetings where designs were discussed and the ease of contacting each other on any matter. Meetings between the customer, foundry, and toolmaker led to the number of ECs decreasing; moulds that were easy to make and lasted longer; quality was understood the same; and the components being easier to cast. When components are designed for casting, fewer disturbances in production occur, and the unit price decreases. In the meetings, awareness of critical points increases. For example, critical measures are understood and can be checked after casting. Additionally, the participants could discuss how the details in design would affect the mould price, which is a significant cost in terms of casting components. Some of these matters can also discussed via e-mail by making comments on 3D-models.

4.2 Communication Analysis

As a basis for analysis, a framework was used. The framework is based on the work of [Maier et al., 2009]. Evidence of poor communication was linked with its impacts and factors that lead to poor communication. The impacts of poor communication and the factors found from our previous study were categorized according to levels. In addition, factors and impacts found from the literature were added to the categorization. The main concepts of information management and communication in design processes found from the literature seem to fall into four out of the five communication levels presented by [Maier et al., 2009]. The product level had only a few factors, which could have been understood to belong to the information category. Hence, the product level was included in the information level. Even so, in a small foundry which worked closely with its customers, no information challenges could be found because the communication was supported on the three other levels. IT has a supporting role in communication. For example, it can be used to enhance collaboration between organizations and people.

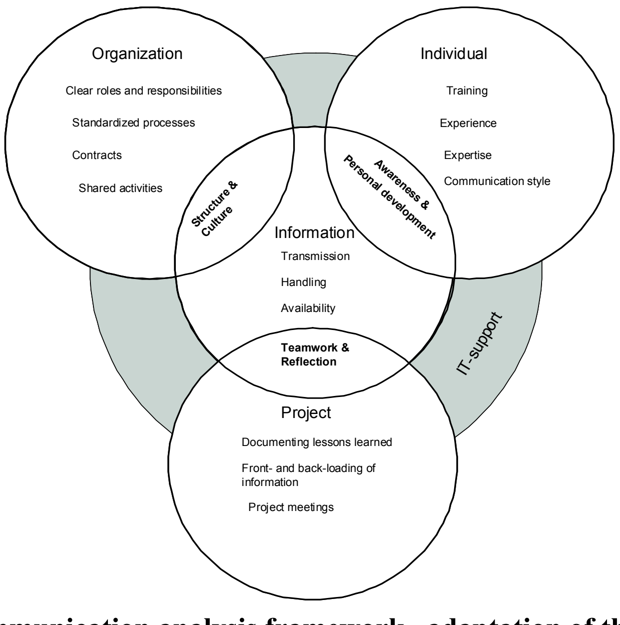

Figure 1. Communication analysis framework –adaptation of the framework from Maier et. al. [2009]

After the factors and impacts were categorized into the four levels, the policies supporting communication on each level were compared between companies. For example, one case company found it challenging that, on an organizational level, whose role it was to inform suppliers about ECs was not made clear. In foundry case companies, where all involved were informed about ECs and discussed them with the foundry, either the designer or the purchaser was in charge of informing the suppliers. With this comparison, the policies that prevented the impacts of poor communication most efficiently were identified. In other words, the factors facilitating efficient communication could be identified. The framework is presented in figure 1 and described in more detail in the following paragraphs.

4.2.1 Organizational level

The organizational level includes the structure and culture of the organization or network, e.g., ways of working. More and more projects are done in company networks; thus, the organizational level needs to be understood as policies between companies and inside one company. The main concepts on this level are roles and responsibilities, standardization, contracts, and shared activities. For example, a non-disclosure agreement needs to be made that confidential information can be exchanged between companies. Equally, standardized processes help to make explicit the communication needs in the process. One designer stated, “We do not have an explicit process, which makes it hard to know who gets the designs or EC orders I make.” This explicit process should also contain roles and responsibilities, for example, who notifies the suppliers of a change.
Example: EC is not implemented in production because production is unaware of the change. Therefore, the designer should have a clear responsibility to notify production of the change.

4.2.2 Individual level

The individual level consists of choices made by the individual, skills, and the awareness of the whole design process. Communication on the individual level relates to training, experience, expertise, and communication style. Individuals who have been trained and have experience are aware of the communication needs of the others in the design process. For example, a designer who has experience and training in casting knows what matters need to be discussed with the foundry and what information the foundry needs to manufacture the components efficiently. To fully utilize the designing process together, they both need to be aware of each other’s processes and the final product. As one of the designers said, “I try to describe our product in detail. I show model parts and components to the foundry. The more information the better.”
Example: Late ECs are made because the foundry’s designer did not know what the component was being used for. These can be diminished by increasing the awareness of the foundry’s designer by presenting him with the concept of the final product.

4.2.3 Project level

The emphasis on the project level is teamwork between the people in the project and the lessons learned from the project. People from different companies need to collaborate to finish the project, e.g., customers order parts from suppliers. Some of the key concepts of teamwork are meetings and front- and back-loading information. In the design process, front loading means, for example, that as much of the production information as possible is brought to the designer for him to design the component for manufacturing. On the other hand, back loading would mean that the designer would visit production to make sure that the design is understood correctly in production, e.g., which surface is visible in the final product. “Parts with visual requirements always need communication to ensure that the visual requirements are understood correctly in production.” Still back loading is usually done at the document level. After the collaboration, the lessons learned need to be acknowledged. Reflection on the project is valued as a means of learning and improving. Documented reflection ensures that the information is not lost when an employee leaves the company.
Example: Rework on redesigning a component for casting. Collaboration with the foundry during the design phase helps make the designs so that the components are easy to cast.

4.2.4 Information level

The information level is comprised of the transmission and availability of information. These are usually highly linked with IT support. Transmission is done via phone, e-mail, IT systems, etc. Problems occur when the receiver does not receive the information, for example, when an e-mail is lost in junk mail. Availability means having the needed information available and easy access to it. People do not need to look for the information they need and access to it when they need it. One interviewee described the difficulty of wasting time on finding information: “As a supplier I need to get the information myself by listening to people talk in hallways.”

Example: ECs are not documented because of poor usability of product data management systems. Hence, the IT tools need to support the documentation process.

4.3 Enablers of Efficient Communication of Quality Design Information

4.3.1 Teamwork

Better quality information could be released if the designer were to collaborate with the people in charge of the downstream activities. For example, casting components can be designed to be cast easier with the help of a foundry casting designer. In the EC case studies, collaboration with other departments and suppliers was seen to decrease the cost of destroying redundant parts, improve the quality of components, and save time because time would not be wasted on finding out what has been changed. In addition, manuals would be up to date because the documenting department would be informed about ECs. Most of the factors leading to poor design information exchange on the project level relate to collaboration with others involved in the process.

Collaboration occurred on a high level in one of our foundry case studies. The foundry and customer had frequent meetings about the design throughout the project. The collaborating parties relied on and utilized each other’s expertise. Many iteration loops were made during the design phase to avoid late ECs. All of the interviewed people found it important to have face-to-face meetings at the beginning of the project. The project meetings included discussion about schedules to ensure that the schedule was not made unnecessarily tight. After the project was well underway, one company limited the collaboration to the document level, and no meetings were held during the foundry’s production. However, other collaborating companies also reported to have meetings during production. Meetings during production would mainly concern feedback from foundry’s production; for example, additional tooling could be avoided by making a minor change to the design. Still no reflection with the foundry was made after the project to see what was done well. However, customer companies held reflection meetings within the firm. Reflection could help to avoid unnecessary costly changes because same mistakes would not be made again in the design phase.

In one foundry case, the customer’s designer also collaborated closely with the foundry during production. The foundry’s casting engineer and the designer would make the test casting together. The designer explained: “I visit the foundry for a couple of days, when we do the test castings”. The designer received immediate feedback on the designs, and the casting engineer was aware of the critical points of the component. The designer would visit the production to see how the components were cast and what caused scrap parts.

In our foundry cases where teamwork was utilized, the main collaborating parties were the foundry’s representative and the customer’s designer and buyer. In the customer company, one designer was in charge of the project and would handle the design information exchange with the foundry. The buyer would discuss the financial matters. It was found easier to collaborate when the number of people collaborating was small. Small groups help to create trust in comparison to a big group or a group that changes all the time.

4.3.2 Individual awareness and development

Frequent and open communication increases the awareness of each other’s processes and products, and awareness is needed to facilitate communication. If people are not aware who they should inform, they do not do it. Likewise, if people do not know that they do not know something, they do not ask for the information. Therefore, designers need to be aware of the information required to facilitate communication in the design process, and they need to communicate with others to increase their awareness of the design. Awareness of the product can be increased by showing the supplier 3D-models, drawings, and prototypes of the component. In the same way, showing the parts that surround the manufactured component helps the manufacturer to get a good overall picture of the product and the interfaces to which the component belongs. Honesty and social ties lead to good communication. One foundry representative told: "First it felt hard to collaborate with the customer, but after we sat down and they noticed that we can say things as they are, our collaboration has improved". Social ties were used to obtain informal information about, for example, how a component could be cast easier. A long career in the same industry resulted in a dense net of social ties, which opened various information channels. One designer told: "I have been in this industry for long and know a lot of people, so I can use my personal relationships to make informal inquiries about the price for example". Having many information inputs leads to increased awareness of prices, materials, design solutions, etc.

Expertise has positive impact on the quality of designer-produced information. Designers produce better designs when they have learned from their past mistakes and experiences. In the foundry cases, the designers who had worked with casting before knew what to ask and when. They utilized the collaboration with the foundry best, even though they were the most competent to design the castings. They collaborated with the foundry on matters that involved only foundry expertise or matters that related to a specific foundry, such as types of machines. To share expertise in the customer organization, new designers were taken to a meeting with the foundry to show them the policy. In one case company, the experienced designer would teach the new designer the requirements for castings set to designs. Documentation of the matters discussed with the foundry was scarce, but the need for such documentation was recognized in some of the case companies to facilitate personal development.

4.3.3 Organizational support

Organizational support facilitates communication by setting clear roles and contracts and by encouraging collaboration on the organizational level. In our foundry case studies, the customers had defined people who contacted the foundry, usually the designer and purchaser, and they had one contact person in the foundry. Communication between the companies was handled through these people. For example, the role of the designer was to communicate matters concerning the design. Nevertheless, communication was not limited to these contact people, which led to more flexibility on informal inquiries; for example, the designer could call the foundry's production to learn the status of the component's production. The designer who contacted the foundry usually had experience with castings so that the communication would be more fluent and focused on the right matters. One designer explained why he is the foundry's contact point: "I'm the oldest and have the most experience. I have knowledge about molds that the more inexperienced designers don't have". In one of the cases where the designer was responsible for informing suppliers about the ECs, the foundry was notified about all ECs.

Non-disclosure agreements were valued as one of the most important enablers of open communication. The contract would make sure that product information could be distributed to the suppliers and that the information given by the foundry would not end up in competitors' hands. In spite of that, sometimes information was given without any contract. For example, the foundry can give comments about designs for free to get the customer to choose them to manufacture the part.

Organizations can increase communication and collaboration through early supplier involvement (ESI). In the foundry industry, ESI is used on complex and strategic parts to design them as well as possible. Choosing the supplier early helps the supplier to give comments before the design is finished, thereby avoiding costly late ECs. Meetings are held to improve the designs. Even though the meetings are not regular and marked to the design process, they were a common policy in our case companies.

5. Discussion

5.1 Challenges

The main challenges of communicating quality design information involved the distribution of information and poor quality designs. Notice of ECs was not given within the firm or suppliers in the traditional manufacturing case studies. The number of ECs was higher in traditional manufacturing case studies because after the casting mould is done, changes to it are expensive; thus, many changes are not done. This could be one of the reasons that ECs did not create that many problems in the foundry industry case studies. Yet if ECs were done, they were so expensive and important that notice was given to the foundry because discussions were needed on how the change could be implemented. Poor design quality was an issue that caused problems, especially in the foundry's production. When designing casting components, some matters always need to be discussed with the foundry, for example, what requirements do the machines of that specific foundry set for the design and how small components can the foundry cast.

As noted by Zhang et al. (2004), support for communication is needed on more than the information level. A common information repository is not enough if the collaborators dot not understand each other [Zhang et al. 2004]. When we asked our interviewees to list challenges in collaboration and communication between the customer and the foundry, no one pointed out challenges on the information level. Information was easy to access and available when support was given on the other levels. For example, the decision to include ESI at the organizational level facilitated communication early in the design process. In our first four case studies, information level challenges were found, and they related mostly to IT. However, some of the information level challenges could have been avoided by support from some other level. For example, ECs were not documented, but the reasons for them could have been taught to other designers, allowing for personal development and avoiding repeating the same mistakes.

5.2 Analysis Framework

Analyzing the found impacts, challenges, and factors through the analysis framework highlights the areas needing the most attention in supporting the communication of quality design information. In these case studies, the policies that affect the communication of design information most were identified based on the number of impacts and challenges it reduces and the depth of the impact it diminishes. The policies behind good communication relate to the organizational, project, individual, and information levels. Approaching communication of quality design information on these levels by categorizing challenges and identifying good ways of working seems to indicate the most useful policies. This is possible because of the cases where the communication occurred on a high level. They gave a good basis for reflection on good policies. Analysis needed to be done to determine why the challenges do not occur in one company when others struggle with them. Although the framework does not list all policies on all levels, it gives a good overall picture of the main concepts on each level. Future work will complement the concepts on each level. The framework does not give a solution to the challenges identified, but highlights the concepts that need attention. Solutions to communication challenges and poor conveyance of design quality information are more domain specific and case dependent. The common enablers of quality design information communication are a good starting point to develop case-specific solutions.

5.3 Enablers of Quality Design Information Communication

Collaboration between people in the design process was shown to improve design information quality, increase awareness of information needs and the design, and distribute information. [Maier et al., 2009] have also highlighted the importance of understanding collaborators' information needs. However, our research does not support the importance of reflection. Reflection was found to be a possibility, but was only used occasionally within firms. More important than reflection was information sharing between the supplier and the customer. Previous work has also shown that the quality of designer-produced information can be improved with ESI, which leads to the number of mistakes decreasing [Clark and Fujimoto, 1991; Hölttä et al., 2009]. This research found policies to utilize this in the foundry industry: meetings with the toolmaker and foundry, test castings done together, defined contact points, etc.

Personal development and awareness was one of the key concepts in improving the quality of design information. Even though some matters always needed to be discussed with the foundry, experience and expertise were found to improve communication and design quality. Experienced designers could design the component to be cast but also knew which matters to discuss with the foundry and when. In many of our foundry case studies, the collaborators had a long history of designing casting components. Transferring such knowledge seemed to be challenge for the future.

Organizational support was needed to facilitate communication within the firm and between companies. The organizational level does not need to support communication directly, but to allow communication, for example, with a non-disclosure agreement. Depending on the size of the company, the amount of standardization to increase awareness of the design process varies. In a small company, standardization is not necessary because of its natural information flow, but in bigger companies, standardization is needed to ensure that information reaches all parties involved.

After mapping the challenges and policies of design information communication, the reasons behind the challenges and policies were compared. How is it that some companies have solved problems that others find challenging? We listed some variables of the case companies. First, company size seemed to have an effect on communication. Small companies had more open and frequent communication. It was easy to ask others, and they did not waste time learning who would know. Another variable was production type. In mass production, the importance of communication increases because mistakes are repeated in every component. In a single series, the need for smooth production is not that great. However, in casting large components, the policy of getting it right the first time is emphasized because cooling can take weeks. This means that if the casting is unusable, it takes weeks to manufacture another. Third, small companies did not have the need for IT tools. Phone and e-mail were sufficient communication tools for them. Hence, no IT problems were found.

The limitation of this study is that the case companies are located in a small geographical area. Case companies were located in Finland and Sweden, and therefore, the applicability of the results in other countries can be debated. However, two of the companies were parts of larger, multinational companies, and their collaboration network includes companies from other countries and continents. Furthermore, similar challenges have been reported by other researchers in other countries. In the foundry cases, all the customers were located in Finland; therefore, collaborating across distance was not studied. Farther distances between companies would mean less face-to-face meetings and the increasing need for IT support for communication. However, one customer company also utilized close collaboration with a supplier abroad, which suggests that these findings can also be applied to collaboration between companies in different countries.

6. Conclusions

Communication of quality design information can be supported on different levels, and three main key factors have been presented in this paper: teamwork, individual awareness and development, and organizational support. In this paper, challenges resulting from poor design information quality have been presented. The quality of designer-produced information can be improved on four levels: the organizational, project, individual, and information levels. The quality can be improved by having the right information, in these cases, better designs by relying on suppliers' expertise during the design phase. Better designs are made by taking manufacturing into account in the design process.

Collaboration with others during the design process ensures that the right information is distributed from the design department. Collaboration also increases the awareness of others' information needs and design requirements. However, actions taken to solve communication problems are domain specific. In the future, we will implement the good policies found in our research to companies where poor quality of design information has an adverse effect on the design process. Moreover, additional research needs to be conducted to determine whether the good policies of a small company can be transferred to a big company.

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