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CURRENT INDUSTRIAL PRACTICES FOR RE-USE OF MANUFACTURING EXPERIENCE IN A MULTIDISCIPLINARY DESIGN PERSPECTIVE

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1. Introduction

The impact on manufacturability due to decisions made during Product Development is well known and approaches such as Concurrent Engineering (CE) and Design for Manufacturing and Assembly (DFMA) [Boothroyd 2002], [Egan 1997], have been used for some time. Despite the significant efforts made in academia and within industry - experiences gained during production tend to remain within the manufacturing organization leaving the opportunities for increased product manufacturability and potential for cost reductions untapped. For that reason, this paper aim to investigate current practices for reuse of manufacturing experience with the objective to identify the best practice and effectiveness of re-use mechanisms. More explicitly, this paper investigates the perceived effectiveness of capturing and feedback mechanisms from manufacturing and production to the design phase.

Two companies are studied, Company A, which is an Aeronautical Engine Components manufacturer, and Company B, which is an Automotive manufacturer.

Company A has a strong history in manufacturing of aeronautical Engine Components and has recently increased the effort to undertake both development and production of these components. Company A collaborates tightly with several different OEM's as a supplier risk and revenue sharing partner.

Company B has a long history of developing cars as an OEM. Over the last 15 years the company has successively developed from an independent manufacturer to a company within a large automotive enterprise. The range of experience obviously covers both development and production of their products over a long time.

In this paper re-use of manufacturing experience addresses how experience found in the production work is made available and eventually used during design of a next generation product (see figure 1).

As seen in figure 1, transferring and using experience from manufacturing in design by definition require a multi disciplinary perspective and is a matter that challenges the learning capability of the organization. How to achieve a learning organization has been a topic for decades [Argyris 1996], [Mulholland 2005]. Still, the question remains whether or not industrial best practice has significantly improved? In the best of worlds the learning organization should already be implemented. In practice however, most industries of scale struggle with recurrence of manufacturing issues.

This study has studied three organizational roles

- The design engineer, who works in the context of product definition
- The manufacturing engineer, who works in the context of manufacturing process definition, and

- The Production technician, who works in the context of (serial) production of the physical artifact.

Four of the product life cycle phases are here covered by the concept phase, the detailed design phase, manufacturing preparation phase and the serial production phase, see fig. 1.
There are different approaches to deal with the topic “reuse manufacturing experience”, covering areas such as data mining [Wang 2007], information sharing, and organizational learning. The knowledge management cycle comprises a range of activities used to discover, generating, evaluating, sharing and leveraging knowledge [Jashapara 2004], [Awad 2003], and is therefore closely related to this topic when it comes to managing experience captured in the manufacturing process. The process of capturing knowledge for reuse of project knowledge has been studied by Tan et al and Kamara et al [Tan 2007], [Kamara 2003], where the focus is set to capturing the experience live in a project. Learning situations identified by Tan et al include weekly site meetings, project reviews conducted at the end of each of the project stages, post project reviews, etc.

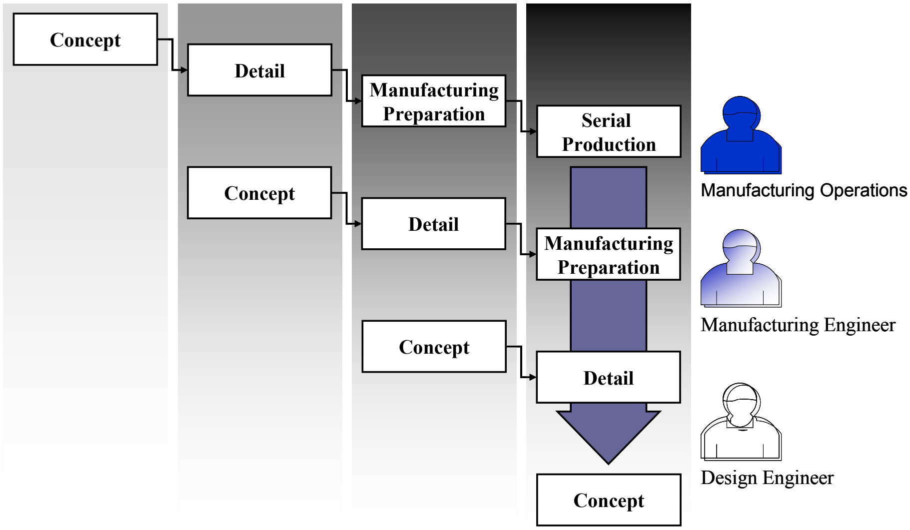

Figure 1. Reuse of manufacturing experience

One mechanism to facilitate experience from manufacturing in design is to work tightly together in product development. This is at least partly the reason to work in multidisciplinary teams following methodologies such as Integrated Product Development [Andreasen 1987] and Concurrent Engineering [Kusiak 1993]. Learning from other disciplines is here enabled since experienced engineers are working tightly together. The effort to make design changes in the early design phases is far less then introducing the same design change in later phases. In combination with the known impact on success factors (Cost, quality and timing) by early design decisions, the early design phase remains a highly interesting phase to improve [Fleischer 1997]. Thomke and Fujimoto [Thomke 2000] highlights two approaches in order to reduce recurring problems; project to project transfer of knowledge and rapid problem solving. Cross-disciplinary teams are consequently a mechanism for re-use of experience.
Methods and techniques for learning from earlier projects within the same phase are done trough both human to human contact, e.g. personal rotation [Kane et al 2005] and non human transfer by utilizing instructions and system support such as databases of earlier projects experiences [Alizon 2006].
What type of knowledge that is important for the engineer has in an industrial case study been identified in order to ensure appropriate training and competence [Ahmed 2007]. Here, Conceptual

design, Value improvements and Detailed design where among the three most important types of knowledge. Tan et al [Tan 2007] has categorized KM tools for capturing and sharing knowledge tool as KM techniques (non IT tools) and KM technologies (IT tools). Post-project reviews, communication of practice, forum and training where he identified as KM techniques and Groupware, documentation of knowledge, expert directory and custom-design software where identified as KM technologies.

The classical challenge of re-using experience from manufacturing can be investigated by;

1. Measuring the recurrence of manufacturing problems over product generations.
2. Investigating the involvement of different disciplines during early phases in design, in the spirit of concurrent engineering and integrated product development
3. Surveying what processes and tools are used for manufacturing experience feedback and their perceived effectiveness.

2. Research methodology

The aim of this study was to describe the current situation in the area of reusing manufacturing experience and to explore what ideas that exist to improve the conditions; hence the "How" and "Why" questions support a case study approach [Yin 2003].

2.1 Case study

Due to the scope of this study, the means and resources available for the data collection, both interviews and questionnaires were used. Interviews, covering a rich and in depth data collection enables a flexible way to sense what is important and focus on that issue, and questionnaires, with multiple choice questions and in addition to these, written comments. Data from the interviews, questionnaire survey and associated comments were analyzed using techniques described in Miles & Huberman [Miles 1994]. The collected information was arranged in different areas with a matrix of categories.

2.2 Survey

Three organizational roles, Design Engineering, Manufacturing Engineering and Manufacturing Operations, see fig. 1, were asked to fill in the questionnaire. 30 respondents within each of the disciplines ended up with 180 forms to analyze. The questionnaires were distributed to the participants and filled in at a meeting were the authors where present. On some occasions the questionnaires were distributed by e-mail. The questionnaire survey was performed prior to the interviews and both the questions and the preliminary result from the survey was used as a basis for discussions in the interviews.

2.3 Interviews

The interviewees were selected on the basis of their profession and position in the company. There were three design engineers and one manufacturing engineer from aerospace and two manufacturing engineers from the automotive industry.

3. Case study findings

3.1 Perceived frequency of recurring problems

Ideally, once a failure or non-conformance is discovered in production, there should be a process that assures that the issue is solved and that experience gained is feed to designers to avoid such failure mode to re-occur. As a first indicator of effectiveness of such process, the perceived frequency of reoccurring issues in manufacturing was studied amongst the three study groups.

The diagram in fig. 2 presents the perceived frequency of recurring problems in manufacturing that the respondents experience in their work. The data originates from rating-scales used in the questionnaire, where the position to the very left was defined as 'never' and to the very right as 'every project'. Each point in the diagram shows the rating from a specific respondent belonging to either Design Engineering, Manufacturing Engineering or Manufacturing Operations, from now on referred to as 'DE', 'ME' or 'MO' respectively. The diagram shows that it is common with recurring problems, although the frequency of them is perceived quite differently among the respondents.

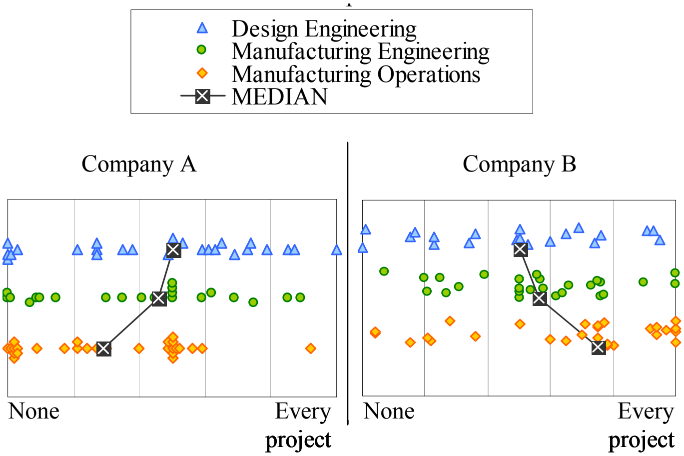

Figure 2. Perceived frequency of recurring problems

Comments in the questionnaire varied between departments; respondents from manufacturing operations gave concrete examples of components that they have been struggling with over the years, whereas respondents from design and manufacturing engineering commented on difficulties with making compromises that where acceptable for all. As a design engineer comments on the question about recurring issues: "*It is usually a result of different compromises where some function had to give way for another.*" Results show that in company B recurring problems were regarded as more frequent among employees in manufacturing operations than among employees in manufacturing engineering and design engineering. The result in company A is quite the opposite, where manufacturing operations tended to perceive the recurrences less frequent than manufacturing and design engineers.

The questionnaire reveals that 61% of respondents in company B state that there are processes to prevent designs that have caused problems in manufacturing from recurring, however only 8% of those think that the processes work. 26% of the respondents did not know if there was a process and the remaining 14% stated that there were no such processes. Company A show a quite different result, with only 11% of respondents thinking that there is a process, and out of those 44% thought that the process was used. 76% of respondents did not know if there was a process for this and 13% thought that there was no process. These results reflect that there are more outspoken processes in the automotive company, although the use of the processes was unsatisfactory.

3.2 Manufacturing competence in the early phases of product development

As a second indicator of effectiveness of the experience re-use, the perceived involvement in early phases of design is studied since cross disciplinary teams have been showed to be effective as a feedback mechanism. Manufacturing experience from earlier projects is usually made available through the composition of new design teams where competence from the manufacturing disciplines is included. Respondents in the survey where asked to indicate their involvement in all four phases, concept, detailed design, manufacturing engineering and serial production. Figure 3 shows the percentage of respondents that believe that they have a higher involvement than "little" or "none".

Manufacturing operations have a low level of involvement in the conceptual phase in both companies. A significant difference between the companies is shown for manufacturing engineers; a little more than 10% of company A engineers recognize they are involved in the conceptual phase whereas more than 45% of company B manufacturing engineers feel they are involved in the conceptual design. The study also makes known that not all design engineers participates in the conceptual phase. Comments to this question reveal that there is a will to have more influence from manufacturing in the concept phase and that globalization effects e.g. that the production is not local, is perceived to have a negative effect on the influence from manufacturing in early phases, which are consistent findings in the two companies. It should be noted that in Company B are the roles of Manufacturing Engineering and *Design Engineering* are organized in the same business organization, whereas in company A, Manufacturing Engineering and *Manufacturing Operation* are organized in the same business organization.

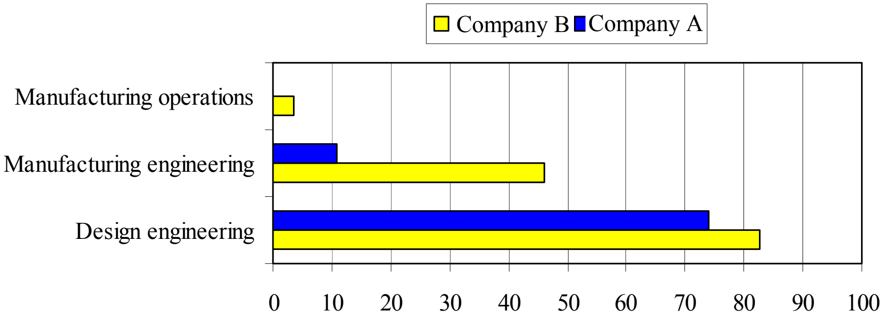

Figure 3. Perceived involvement in the concept phase

In addition to the study of involvement in early phases, the perceived contact between design engineers and manufacturing engineers was explored. Respondents from design engineering were in this case asked to answer to how frequently they are in contact with manufacturing engineers in the different product development phases and manufacturing engineers were asked the same question about design engineers. Fig. 4 illustrates the percentage of daily or weekly contact and the result reveals a difference between company A and company B. The difference in perceived contact is significant between the design engineer and manufacturing engineer in company A in early phases.

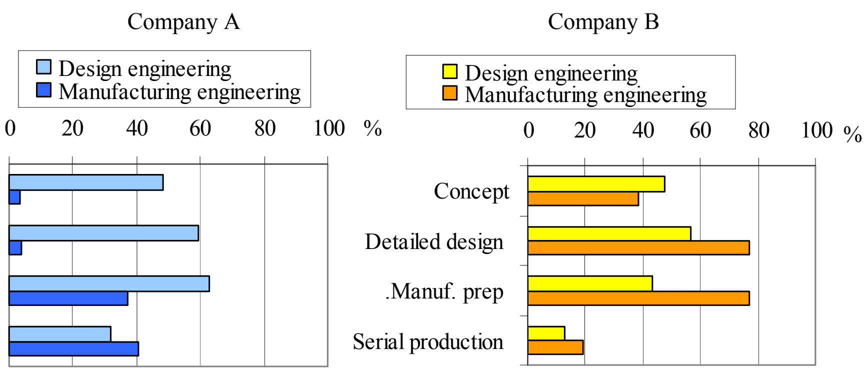

Figure 4. Design and manufacturing engineers perceived contact

The three most frequently used means of communication were identified in the survey as: telephone calls, e-mail and small meetings. Surprisingly low was the use of IT-tools for sharing desktop information; less then 5% of the engineers have indicated this tool as one of there 5 most common mean for communication.

3.3 Systems for manufacturing experience

Finally, the process and systems support for feedback of manufacturing experience has been investigated since existence and use of such systems are often emphasised in company initiatives to improve feedback of experience and make information available for later work.

Several systems for feedback coexist in both companies and there are also different ways of using them. In company B there are global databases where specific lessons learned documents and best practices are stored; however there are not that many entries from the Swedish site. Lessons learned can also be an activity at the beginning and end of a project where experiences are documented during a five-hour session, resulting in a report covering the issues, countermeasures and introduction dates. Manufacturing operations have another lessons learned system that is used for sharing good ideas about industrial engineering among the factories in Europe, se Fig 1. Experience reports are used in parallel with the new systems across the organization and are either continuously updated or created at project endings. Another source of documented experience from manufacturing is a database with statistics from an in-line system in the plant that collects measurement data from every vehicle that is produced of a specific model.

Table 1. Survey of tools available for -use of manufacturing experience

Company A	Company B
Lessons learned database for design engineers in Lotus Notes	Lessons learned documentation stored in local file areas or in the ERP System
Best Practices database for design engineers on the intranet	Issue reports for tracking problems in ERP System
Global database for standardized manufacturing processes for manufacturing engineers	Design Practices database for design engineers on the intranet
Lessons learned database for manufacturing operations on the intranet	Database with measurements from all manufactured components used by manufacturing operations
Experience reports from concluded projects on local file areas or in physical folders	
Database with in-line measurements used primary by manufacturing operations	
Database for tracking problems in manufacturing	

Company A has a product development process that specifies that lessons learned should be reported at every gate and also consulted at certain points. However, this has not come fully into practice and there are not that many lessons learned available since this has recently been introduced. Experiences should be documented at the end of each project; however these reports are often filed on electronic project areas with restricted access. Design practices are created and managed by workgroups in organizational development work. There does not seem to be a process that triggers an update or creation of a design practice and employees express a lack of them. Similar to the automotive company, there is a vast collection of measuring data from manufacturing. This data is only used by manufacturing, even though the information would help design engineers to know more about the current manufacturing capabilities.

When design engineers were asked to rate how valuable best practice and lessons learned documentation is in their work, the response were quite scattered. Notably, 21% resp. 23% of the respondents was unaware of any lessons learned at all. Comments from the respondents were that it is difficult to find relevant information in the documentation.

4. Discussion

Two observations were evident from the study. One is the visible differences between the companies in the responses, and the other is the differences when comparing the response between different disciplines.

The first observation is for sure impacted by the history and role of each company but also, at least partly, reflecting the difficulties in achieving an effective system for re-using manufacturing

experiences in design. It is noticed that Company B has a more developed system to manage experience and are more aware about their processes for capturing manufacturing experience. Still, Manufacturing Operations convey an even higher frustration over recurrent manufacturing problems. One possible explanation could be that an increased awareness of the complexity of problems increases the receptivity and also the motivation to solve the problem. Explanations may also be found in the fact that Company B produces a car – a consumer product that can easily be related to and also a complete system. Company A produces engine components (each of the same cost and value as a car) but the complexity is of a different character when it comes to manufacturing.
The second observation, that experiences are captured and used by different disciplines, in different context is interesting. Typically, a vast amount of documentation is stored in databases and project areas and re-use is limited (in both companies). One suggestion is to update instructions and best practices according to selected lessons learned that are considered the most important for future products. Lessons learned activities at project start ups is a good opportunity to learn from the previous project, but can not replace the benefits of standardized best practices in the long term. Converting lessons learned into best practices may also help design engineers in the sense that there is no need to distinguish when lessons learned from similar cases apply to the current situation.
More principally, the challenge is how to contextualize experiences from the "capture" context to the "use" and "re-use" context of design.

5. Conclusion

Three plausible mechanisms for re-using experiences from manufacturing in design were studied empirically at two manufacturing companies. As an indicative measure of effectiveness of re-using experience the perceived re-occurrence of manufacturing problems between product generations was gathered and revealed the percentage of reoccurrence was significant at both companies but higher at the Company B which have a longer tradition of own product development. Secondly, the involvement within early phases of design was studied, and the most significant result was that Company A had a fewer number of manufacturing engineers participating in design than within company B.
Finally, the amount of formal processes and dedicated systems for feedback was higher in Company B that in Company A. Yet – the awareness and perceived effectiveness of systems and processes were low at both companies. In addition, the risk of "information overflow" is apparent once the formal systems for capturing experiences are used. As the amount of information grows, it is known from interviews in the automotive company that design engineers prioritize other engineering tasks and are reluctant to follow the procedure to go trough the sources of manufacturing experience.
The conclusion is that despite long term experience and existence of both formal processes and IT systems, the perceived effectiveness of how to re-use manufacturing experience in design is still immature.

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