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A PROCESS IMPROVEMENT APPROACH TO CAPITALIZE ON MANUFACTURING EXPERIENCE IN ENGINEERING DESIGN

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ABSTRACT

The ability to capitalize on company knowledge and experience earned in various projects is recognized as key assets in the competition on the growing global market. Methods and tools are constantly evolving, still there is a frustration over repeated design flaws and design engineers has a difficult task to find and use manufacturing experience from earlier projects.
This paper outlines a process improvement approach where the engineering process is described and analysed to find bottlenecks. Examples from other engineering processes are presented along with a prototype of a knowledge application to resolve identified issues with the manufacturing feedback process.
Experience and knowledge are closely related, hence a knowledge life cycle explain the different steps with a “capturing” and “deploying” side.
The feedback processes for manufacturing experience is analysed where search & find together with contextualisation of experience data are recognised as key mechanisms. A knowledge application is presented that presents experience data from different repositories in a way that is logic for the receiver. This reduces the lead-time and increase the quality of the feedback process.

Keywords: process improvement, engineering automation, manufacturing experience

1 INTRODUCTION

Improving performance in Product Development to gain or improve competitive advantages can be achieved by either reducing cost and lead-time or improving quality of the process itself. The actual process to follow during product development can be described in a Product Development Process (PDP) wherein methods, tools and practices can be described. Certainly, the result when following the PDP process to some degree depend on what methods and tools actually are prescribed, and the skills of the people actually working.

The research work presented in this paper addresses the experience aspect of product development – more specifically the experience gained in production and how it can be used up-streams in the process where the product definition is set. There is definitely an important dependency between the manufacturability and the definition of the product. Experience thereof appears in the manufacturing process, or in the preparation of the manufacturing definitions. The most significant contribution from a scientific point of view is the description of a process improvement approach to improve the experience feedback from manufacturing to earlier phases in the product development life cycle.

We will introduce some mechanisms for experience management using a “Knowledge Life Cycle” and briefly review how experience is addressed within the domains of knowledge management and engineering design. These mechanisms were extracted from a combined interview/questionnaire conducted within two manufacturing companies [1].
Following the brief review, we present a process approach to identify bottlenecks for experience processes in order to capitalize on manufacturing experience when defining new products.

1.1 What can be considered as manufacturing experience?

Experience is closely related to knowledge or, as defined by Longman dictionary [4] of contemporary English; "*the gaining of knowledge or skill which comes from practice in an activity or doing something for a long time, rather than from books.*"

Knowledge can be in the form of tacit or explicit as described by Nonaka et.al. [2][3] and in the SECI model tacit knowledge is crystallized into explicit knowledge. Nonaka et. al. have built their theories based on the ancient Greek philosopher Plato, "Knowledge is justified true belief" where the focus is on "justified" rather than "true". Nonaka describes how information becomes knowledge when it is interpreted by individuals, given a context and anchored in the beliefs and commitments of individuals.

Manufacturing experience is consequently limited to experience gained in the manufacturing process. Typically, manufacturing experiences are recorded in its explicit form (documentation, data-logs, statistical databases etc) in various forms and repositories. Note that tacit experiences are "stored" in the memory of the people involved. Examples of where most experiences are recorded in the two studied companies [1] are;

- Databases for process capability data (Experiential data)
- Databases for issue[1] reports
- Databases for lessons learned reports

These sources record the factual data about manufacturing experiences, whereas the contextual information important to interpret the facts reside in yet other tools such as the CAD CAM system.
In the CAD CAM tools, drawings for both the product definition as well as all the manufacturing process definition preparation are defined and modelled. Such information can be crucial in the design engineer's task to understand the capability data and issue reports since the manufacturing process model represents the context of the data.

1.2 The contexts of design engineering and manufacturing engineering

Since within most medium-sized and large organizations, different organizations and disciplines perform the actual manufacturing and the product definition work respectively, there is a natural challenge to capture relevant experience and communicate this experience to designers. Even if experience is captured and communicated, it is not always apparent how the experience should be used. There simply exists a series of pit-falls on the way from the learning occasion to the occasion where the insights are used to define a forthcoming product. As we shall see there are a number of issues that can be identified that has an impact on how well experience from manufacturing can be capitalized on when designing products.

At first – comparing the stages when the product is defined with the stages when the product is being manufactured quickly reveal a number of challenges from a knowledge transfer point of view.
The designer's context differs from the manufacturing context in several ways [5]:

1. Different people actively involved in design and manufacturing
2. Different organizations
3. Different time scales and life cycle phases
4. Different work objectives
5. Different tools and systems used

In short – manufacturing and design provide different contexts. We label these contexts "the design engineering context" and the "the manufacturing engineering context".

The *design engineering context* is characterized by the fact that there does not exist a product (yet). In stead – the engineers work with translating needs and requirements into feasible- and ultimately -

[1] Issue Report : Also, "Incident report", "non-conformance report" or "problem report".

verified solutions. Indeed there exist an awareness about that the definition of the product has a great impact on how well the product can be manufactured and produced, but this is "merely" one of the many conditions to balance when creating a product definition. The customer expectations must be captured and understood, and typically described as design requirements. These requirements are often functionally oriented, driving the properties expected on the product in service. Manufacturability is a necessary "constraint". The relative importance of this "constraint" verses the more functionally oriented requirements may depend on what type of products are developed.

People, systems and tools are thus primarily aimed at creating and evaluating product definitions.

Experiences from manufacturing are being brought into the process using techniques such as DFSS [6], DFM and DFA techniques [7] and by using multi disciplinary teams in a Concurrent Engineering setting [8].

The *manufacturing engineering context* has a different setting. The product is typically completely defined and the first task is to complement the product definition with a manufacturing definition. Later, as the manufacturing definition has been defined, the work is focused on the actual manufacturing process and the entire production process (assuming that production is a super-set of manufacturing). Since the actual production process focuses on the material flow and throughput of new products, the people, their methods, tools and systems are dedicated to support this flow.

The above description is somewhat stylistic, since the product and process definition are defined in parallel (or even integrated), but still highlights the contextual differences that still reveal the major difference – the different focus of the work.

From an experience management point of view this is unsatisfactory since transfer of experiences need to overcome these context differences.

2 THE PROCESS VIEW

Engineering work can be described in processes, where based on given input the output from the process is generated following the activities that build up the process. This is a common way of representing work, and was used at both studied companies to organize work. The process description is then an important mechanism to facilitate best practices. Processes can be studied and used from many different viewpoints, and process improvement is a continuously on-going activity at most companies.

The process for capturing experience from design and manufacturing phases is discussed by Giess et al [9] as they identify two types of working modes, synchronous and asynchronous as well as the types of information associated with each mode. Synchronous work mode is where the engineer works on the same activity at the same time, in opposite to asynchronous work mode where they distinguish two separate forms of activity, the learning and transactional. "A transactional activity is one where manipulation of information takes place according to an established process and further information is created." Different tools and processes are involved as the design activities vary from brainstorming to decision making. Mela, et. al. [10] identifies enabling factors for managing intellectual resources in engineering design, where understanding the synthesis formed by internal operators and processes being one of the important mechanisms.

Another important characteristic of process descriptions, are that these can be modelled and simulated to predict functions and properties of forthcoming output from processes.

The use of process simulation is presented by Giaglis et. al.[11][12] and in his paper "Integrating simulation in organizational design studies" he investigates the efficacy of business process simulation (BPS) in the context of the process paradigm of organizational design. Derived from a generic approach to simulate model development advocated by Law & Kelton [13] and generic business redesign methodology advocated by Davenport [14], Giaglies et. al presents the ISEC methodology for incorporating business process simulation in a process change. The methodology consists of four main phases; Initiative, Simulate, Experiment, Conclude, which can be further decomposed into a number of more detailed steps.

To measure the effect of process improvements, we need measures that are not trivial. The problem of measuring improvements in the design process is recognised and described in the introduction of the book "Design process improvement; A review of current practice" by Clarkson and Eckert [15].

In this paper, we use process formalism as a way to represent workflow in engineering processes. We follow a process improvement approach which is described as follows;

1. Capture and represent the actual engineering process
2. Identify bottlenecks
3. Identify actions to correct the bottlenecks
4. Develop alternatives to facilitate and automate "knowledge flow"
5. Validate by applying the new process

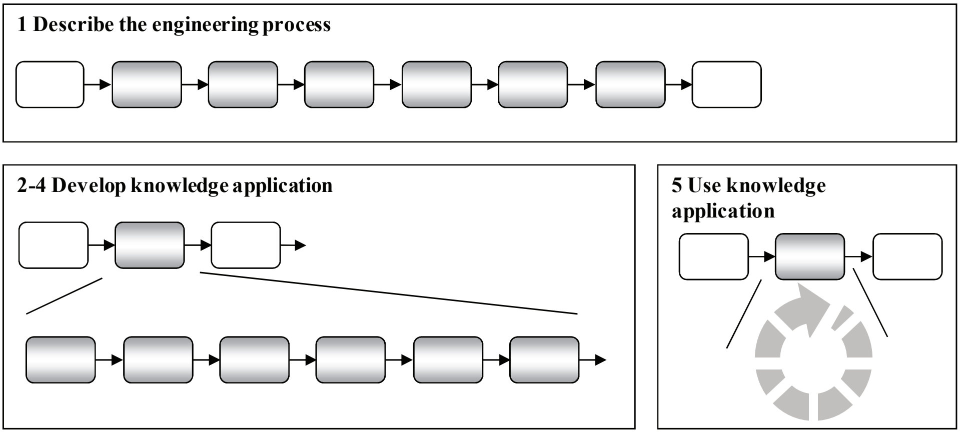

Figure 1. Process Improvement approach for knowledge applications

As an example, we map out engineering design and analysis processes below. The approach to analyse an existing engineering process and automate tedious and iterative tasks has been proven efficient for CAE tasks such as Pre-processing for structural analysis [16], and Automated CFD blade design within a CAD system [17].

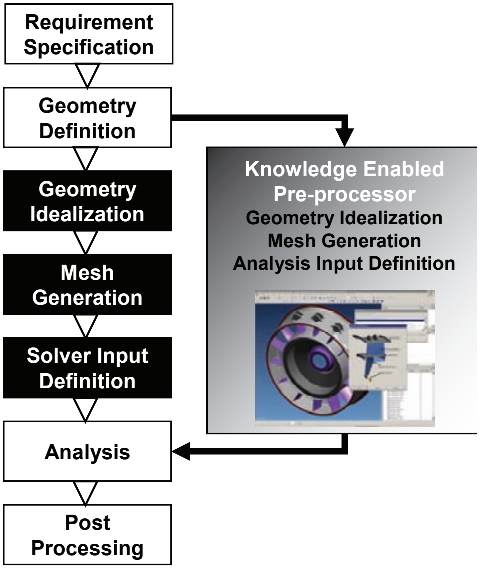

Figure 2. Process model for knowledge automation applications

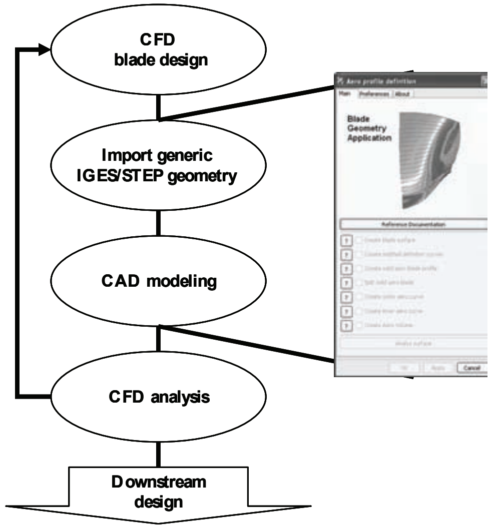

Figure 3, Illustrating design flow to generate CAD geometry

Figure 2 illustrates an example where engineering activities in an analysis process for jet engine components have been automated to achieve a more efficient process with shorter lead-time and improved quality, enabling the engineer to iterate more design concepts and get a better understanding when making decisions.
Figure 3 illustrates another example where the task of generating aero-surfaces in CAD software has been automated and shortened the lead-time as well as improved the quality of the engineering process.

We now present how the process improvement approach has been adopted to an experience re-use process rather than on process automation.

2.1 An knowledge life cycle process of experience

Experience and knowledge are closely related and can be represented in an 8- step model called the life cycle of knowledge.

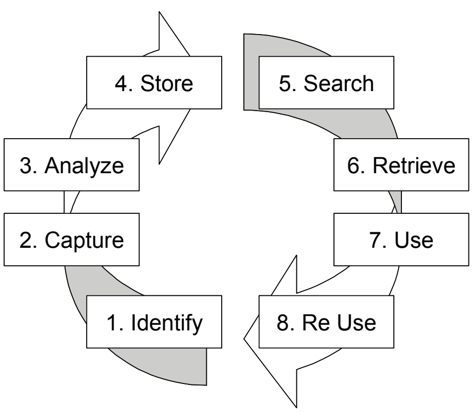

Figure 4. Life Cycle of knowledge

The process starts with *Identify* (1) - the actual occasion where the experience occur. In practice, this can be a non-conformance that appear in manufacturing due to an ill-defined product definition feature. The "experience" is made only if anticipated as such. If not anticipated as experience it is merely information and data about an instance or incident. The effect is observed by, let's say an NC machine technician who recognizes the problem and most often solves any immediate problem in some way. Secondly, if considered/judged as important the "experience" can be *Captured* (2). Commonly it is only data about the symptom that is recorded, and sometimes complemented with an incident report. This report documents the circumstances valid as the occasion governing the experience was happening. Often, it is first when *Analysing* (3) following the capturing activity that the root causes and the more wider term *experience* can be clarified. The insights from the analysis may be recorded, *Stored* (4) in some format and archived. The way that the experience is stored is decisive for how the experience can be searched (5) for. Typically, to use (7) experience the design engineer need to search, retrieve (6) and compile experience elements from different sources before the adopted experience can be used in a proper way. Finally, we've added an 8^{th} step where the use of the experience is built into some system so that it can repeatedly be reused.
Note that non of the steps mentioned above states any means or media for e.g. storage and search. This means that experience can (and usually is) stored in a human mind, and the search method can be to ask someone who knows. Obviously, the storage media can be a digital document archive or a process description where experiences can be stored in a re-useable format.

We further note that there are two major streams in the experience management process. The "Capturing" side to the left (1-4) and the "deploying" side to the right (5-8).

Seldom is this "process" made explicit in a company Product Development Process, but rather loosely outspoken as a general call for making use of experience in the organisation combined with key support systems such as records- or document- management system and a set of instructions.

2.2 Push and pull, mechanisms for experience feedback

We now recognize two mechanisms for experience feedback based on the Design Engineering context and the Manufacturing engineering context introduced earlier.
From a designer's perspective, experience can be pulled from sources of experience data using search and retrieve strategies (5-6). Experience can be found as manufacturing process capability data as recorded from each machine or operational process step. Experience is also found in document records in the form of problem notifications and lessons learned type recordings.

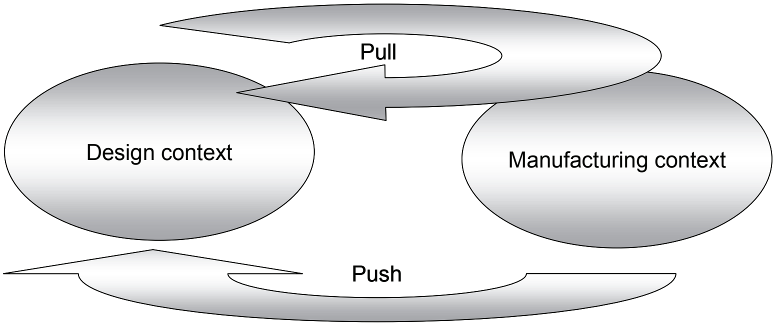

Figure 5. Experience can be "pulled" from manufacturing as well as "pushed"

The second alternative, called "push", is where a fault or incident appears somewhere in the manufacturing phase (1-2), and the post-analysis of the root cause (3) trigger a process to update the company design system or organization. This can be in the form of improving existing design instructions & best practices or define new ones, improve education material or other means necessary to prevent similar faults or incidents to recur. Basically, make sure that the lesson is learned for not just the particular project but also for other ongoing and future projects (8).

The difference between the 8th step (re-use) and the 7th step (use) is related to single loop learning and double loop learning as described by Argyris [18] already 1977 in his paper “Organisational learning and management information systems”. Argyris example for a typical single loop learning is a thermostat that turns on or off to keep a specific temperature because the underlying program is not questioned. Here, Argyris point out that “*The overwhelming amount of learning done in an organisation is single loop because it is designed to identify and correct errors so that the job gets done and the action remains within the stated guidelines. The massive technology of management information systems, quality control systems, and audits of quality control systems is designed for single loop learning.*” This is still true as presented in the case study at two companies in 2007 [1]. Our Re-Use step (8) is intended to implement the double-loop learning mode in a process that can be defined in a company process.

Relating to the life cycle of knowledge described in figure 4, the analysis of the root cause (3) identifies the immediate problem within the project and is not traced back to the design phase. An example of single loop learning mentioned in the case study was a car door that was difficult to assembly and a special instruction was invented to guide the production engineer. This action solved the immediate problem and reduced the lead-time significantly. However, the event was not reported and dealt with at the design department. Hence, the design flaw could possible be repeated in the next project. No double loop learning was achieved, and no “re-use” action was taken to update the design procedures for door design-for-assembly.

To both deal with the immediate problem at hand and also update the design process is what Argyris describes as the double loop learning, or as in his example, having the thermostat questioning its order.

3 AN INDUSTRIAL EXAMPLE

The process improvement approach described above has been applied onto an example, here looking at the right side of the knowledge life cycle in figure 4, step 5-8.

The study mentioned in the introduction [1] identified two major repositories that stored useful experience type of information, nevertheless where these repositories seldom used by the design engineers. These repositories contained issue reports and capability data that could be used when making decisions on design concepts that where similar to existing products already in production.

The reason for not using this information was stated in the study as difficult to access and in addition, difficult to understand. To understand the experience flow the process for retrieving issue reports and capability data where explicitly modelled and analysed. The current process for search and retrieval of experience information is presented in figure 6.

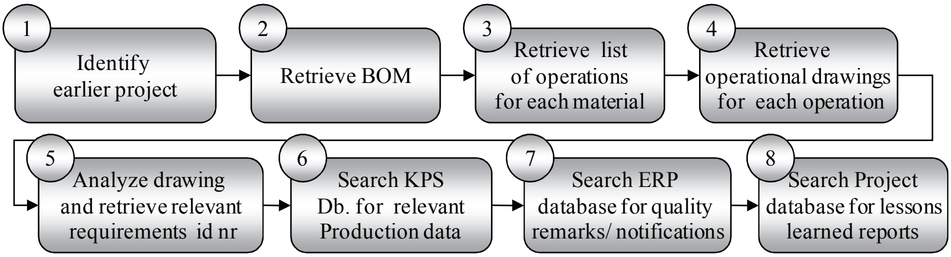

Figure 6, Current process for retrieving capability data and issue reports from earlier projects.

Figure 6 describes the process steps to retrieve capability data and issue reports from a similar design in earlier project;

1. Identify earlier project that has similar design characteristics (System 1)
2. Retrieve Bill Of Material (BOM) (System 1)
3. Retrieve list of operations for each material (System 1)
4. Retrieve operational drawings for each operation (System 2)

5. Analyse drawing and retrieve relevant requirements id nr (System 2)
6. Search KPS database for relevant production capability data (System 3)
7. Search ERP database for quality remarks/ notifications (System 1)
8. Search Project database for Lessons/ learned reports (System 4)

The process to retrieve manufacturing experience such as capability data and incident reports involved several steps and the engineer had to search in several different IT systems, hence the process was found to be tedious and time consuming. Another problem with the process was that it was difficult to interpret the data. This can be explained by the difficulties to correctly interpret and recreate the manufacturing context. Capability data and incident reports are captured with the intention to monitor and optimize the production process, hence, the data is organised to follow up a specific machine or production line. This is in contrast to the design context where the interest often is to ensure the robustness of a specific design of a feature, such as a flange or an engine mount.

The approach to improve the process was then formalized to solve the issues with several manual steps in multiple IT systems and contextualisation. The information modelling technique used to solve the issue is described in a previous paper [19].

Figure 7 illustrates the application that presents data from several sources presented on one page, providing the engineer information in a design context.

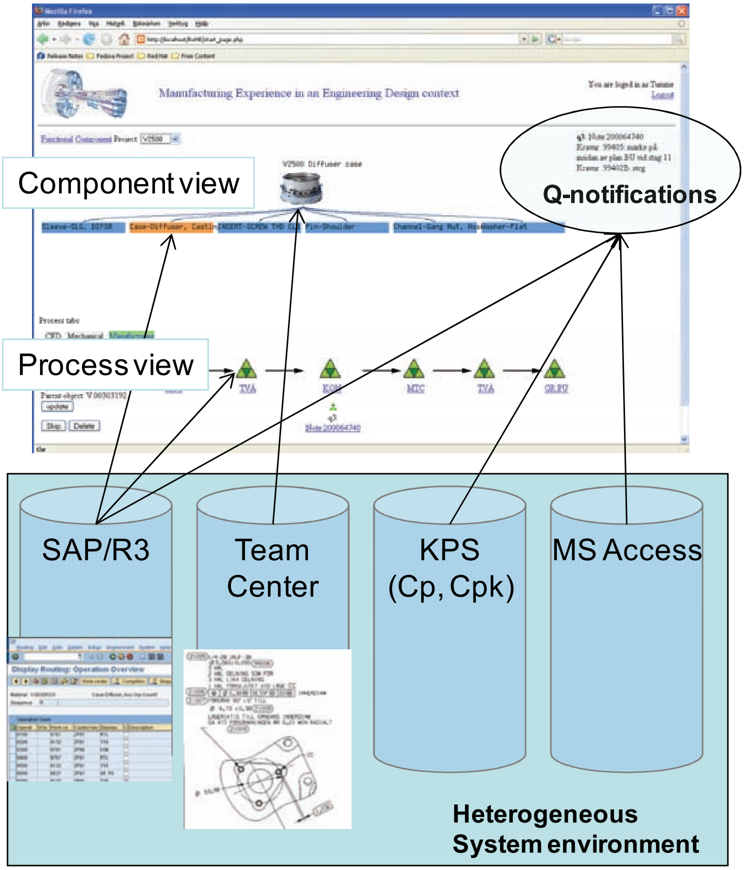

Figure 7, system support to automate search and access to reduce the lead-time and proved a better understanding of the data presented.

Visible features in the graphical presentation are; project filter, enabling the engineer to choose previous projects. A component breakdown displays the assembly structure of the product and by choosing a subcomponent, the corresponding list of operations reveal the manufacturing process. In addition to this, quality notifications generated by an activity in the process is displayed and easy to access.

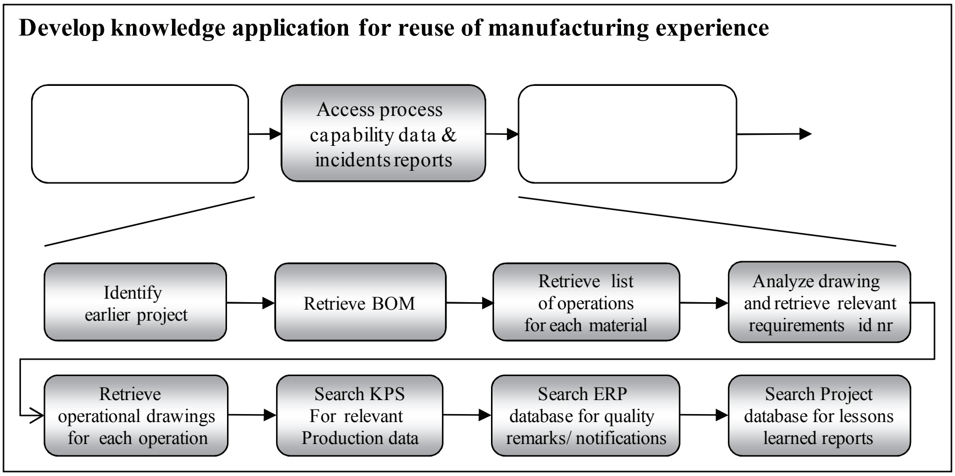

Figure 8, system support to automate search and access to reduce the lead-time and proved a better understanding of the data presented.

Figure 8 uses the process improvement approach described in chapter 2, and applies the same approach to the experience process. The knowledge application automates a series of steps and accesses data from several system repositories. The first gain from adopting this process approach is that the search and retrieval process is automated and lead-time to retrieve data is reduced significantly.

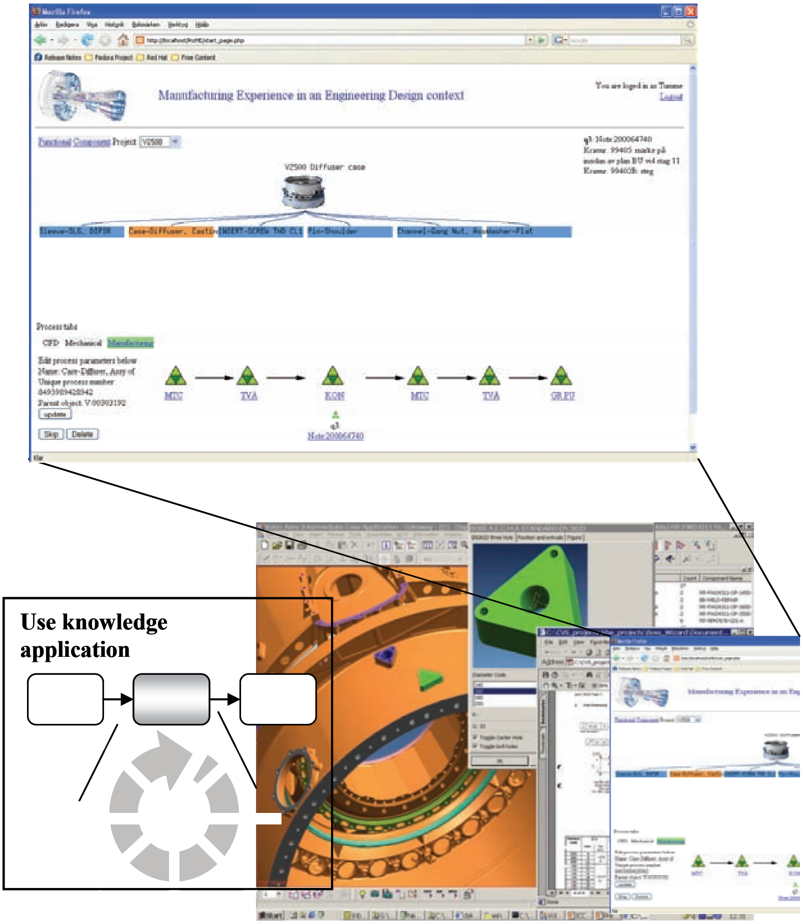

Figure 9, Providing the information in the context of the design engineering

Figure 9 illustrates the integration of a knowledge based engineering tool with the developed knowledge application, providing the design engineer the right information at the right time. The result from the search and retrieve activity is presented in the designer's natural system environment. When modelling a CAD feature, such as the "boss" in figure 9, process capability data and incident reports from previous projects are visualized in a context that is logical to the designer. This second gain is about presenting the results in a context known to the designer.

4 SUMMARY AND CONCLUSION

The rationale and justification of this work are based on the documented results in a previous study of two larger industrial companies where the feedback process for manufacturing experience was identified as a weak spot.

A knowledge life cycle model was used to present the different steps involved in the feedback process of manufacturing experience.

The process improvement approach is represented as a series of steps to analyse and improve the engineering process.

1. Capture and represent the actual engineering process
2. Identify bottlenecks
3. Identify actions to correct the bottlenecks
4. Develop alternatives to facilitate and automate “knowledge flow”
5. Validate by applying the new process

Using the manufacturing experience feedback process, the bottlenecks were found to be difficulties in finding and accessing the manufacturing data and it was also difficult to understand and analyse the effect of the retrieved data.

The plausible causes for this were found to be;

- Context difference between design and manufacturing
- Incompatible, and multiple, sources of information

The approach was validated by building a prototype knowledge application that facilitates the use of manufacturing experience in design using context search from two different business projects. The prototype tool demonstrates a new improved work process with respect to lead-time, quality, and number of activities and contextualisation as a mean to support understanding of the data.

So far, the fact that manufacturing experience can be assembled and retrieved in the users (engineering designers) context significantly contributes to awareness and accessibility of experience at the decision situation.
To conclude, the use of a process improvement approach to enhance the use of manufacturing experience in design shows promising results.

5 FURTHER WORK

To further evaluate the proposed solution in a business perspective, it is necessary to deploy the knowledge application in a business product development project.
There is also a challenge to integrate the suggested approach in the company’s IT environment. Experiences from the work presented in this paper indicates that there are several difficulties that has to be solved, both concerning access to key competences of IT personnel as well as adopting to company IT strategy.

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