ECO-Boat MOL Capturing Data from Real Use of the Product

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Abstract. In many industries, such as leisure boat production, product design and process engineering are often based on diffuse criteria and a lack of data about the actual use of the products. If design and process development are not based on facts, there is a great risk of setting the wrong quality criteria and performance requirements. In the leisure boat industry the lack of data from how customers actually use their products results in product design based on experience (looking backwards), subjective judgments and input from certain customers or key persons. This often results in too high or wrong quality standards and consequently over-processing. ECO-boat MOL has studied this situation in the leisure boat industry. The paper describes how this research project has approached the need for more fact-based design through three different sources. The project also (re)defines work processes in design and production that take advantage of the new data and information.

Keywords: Middle of life, leisure boat production, fact-based design

1 Introduction

1.1 Facts and sustainability

Sustainability and social responsibility is increasingly regarded as a prerequisite for manufacturing industries. The implication for manufacturing companies is that products and processes need to be designed so that they have the most positive impact on the environment along the lifecycle including all the phases, Beginning of Life (BOL), Middle of Life (BOL) and End of Life (EOL).

Succeeding in this regard requires large amounts of facts and knowledge that should be used in the design-phase. To a large degree, such facts and knowledge are generated during the Middle of Life (MOL) of the lifecycle, i.e. the phase where products are used and actually meet their "reason d'etre". MOL is also the phase which is normally the basis for manufacturing companies' existence.

If design and process development are not based on facts we have a great risk of setting the wrong quality criteria and performance requirements. In such a situation we

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risk to create and design products that do not meet the real customer requirements. We also risk developing inefficient designs and production processes if we solely use experience or beliefs instead of facts.

To avoid risks of products not meeting the promised and expected quality requirements, e.g resulting in claims or rework, the producer will often define higher quality standards than required from their products' actual use by their customer. This is an important source for over-processing and waste in the production. Reducing over-processing could not only have important impact on company costs, but at an aggregated level this is also an important issue in our common efforts for a more sustainable production. On the other hand, if companies based on a lack of facts make products that do not meet the real customer requirements; they might meet serious problems from e.g. claims, accidents, rework, and reputation.

1.2 SME's and knowledge creation

First defined by the Brundtland Commission in 1987 [1], a typical definition of sustainable manufacturing is [2]: “the creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound”.

We are not familiar with research proving that small scale production or SME's have e.g. a more negative social impact or negative impact on the environment. Depending on manufacturing context, strategies etc., we also often see SME's producing as resource efficient as larger manufacturing companies. However, there are certain challenges for smaller companies and companies that are not volume oriented. One such challenge is related to knowledge creation and knowledge transfer. Obviously these problems are often linked to resources and capabilities available in the companies. Capturing and making use of these data requires not only systems and hardware solutions, but also the design of processes to make use of these kinds of data in design and production. This could be very challenging for example in low-volume production and where production processes are not standardized. These characteristics we often find in craft-manufacturing and extreme customization. The leisure boat industry is an example containing many of these characteristics.

1.3 Scope – fact-based design in the leisure boat industry

In the leisure boat industry, the lack of data from how customers actually use their products, results in product-design based on experience (looking backwards), subjective judgments and input from certain customers or key persons. This often results in too high or wrong quality-standards and consequently over-processing. The need for more fact-based design has resulted in a research project (ECO-boat MOL) aiming to change this situation radically.

The aim of this paper is to describe the challenges for leisure boat producers in design and production and how the R&D project ECO-boat MOL is approaching the need for more fact-based design through data collection.

The composition of the paper is as follows. Section 2 presents some theoretical perspectives related to knowledge creation in a SME-context. Section 3 presents the project ECO-boat MOL and the cases studied. Section 4 is a discussion of possible solutions to the challenges related to fact-based design and process-development aiming to improve product-development and consequently reduce over-processing. Section 5 summarizes preliminary findings and conclusions.

1.4 Case-study as research approach

The paper is based on case-studies from the research project ECO-boat MOL. The project has four industrial partners, three Norwegian boat builders and one supplier. There are also three Norwegian R&D partners (SINTEF, University of Agder and INVENTAS). The project is co-financed by The Norwegian Research Council.

The project started in August 2011 and the activities so far have been studies for identification of knowledge requirements and how MOL-data could improve business performance. Detailed SWOT analysis in the different case companies have been an important part of these studies. The workshops have been prepared and monitored by the researchers, aiming to create hypothesis and ideas of possible solutions for the companies.

Case-studies lend themselves to both generating and testing hypotheses [3]. Yin [4, p.1] defines the scope of a case study as "an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident". The research project ECO-boat MOL aims both to generate hypothesis and testing them through concrete solutions both for data collection and process development in design and production. However the research at this stage of the project and the results presented in this paper are mainly concerned with generating hypotheses.

2 Theoretical perspectives – sustainable manufacturing based on facts

2.1 Sustainability

Many manufacturing companies have been 'forced' to think social responsibility and sustainability through regulations, new standards or public pressure towards greener products. However, many companies have also approached sustainable manufacturing using a more visionary and proactive approach with the belief that their actions on these issues will make a difference. Industries have traditionally addressed pollution concerns at the point of discharge but this end-of-pipe approach is often costly and ineffective. Thus, industry has increasingly adopted cleaner production by reducing the amount of resources and energy used in the production process, and a focus on environmental friendly energy sources and materials. Allwood [5] focuses on the relation between the "ecosphere" and "anthroposphere" where sustainable manufacturing is about developing capabilities to transform materials without emission of greenhouse gases, use of non-renewable or toxic materials or the generation of waste.

One of the challenges in making strategic decisions will be to make tradeoffs between economic vitality, environmental protection, and social progress (i.e. sustainability). Decisions about processes and products will obviously have consequences for social progress and environmental protection. Choosing a manufacturing process that could damage the environment would violate the philosophy of sustainable manufacturing, even if it strictly from the company perspective could be the most efficient. In the same way supply chain decisions would be different when the supply chain partners' attitudes impacts on the environment are also brought to the table.

This also implies that many companies now are considering the environmental impact throughout the product's lifecycle and are integrating environmental strategies and practices into their own management systems. This means that sustainable manufacturing should be seen in a life cycle perspective covering all three aspects and all three elements: social, environmental and economic. This view on sustainable manufacturing requires a lot of efforts and collaboration with a wide range of actors and a strategic basis for manufacturing decisions.

As the focus and perspectives in manufacturing have developed over time, the changes have often been described as shifts in paradigms, "a set of beliefs that guide action" [6]. These paradigms are not absolute in terms of complete frameworks for how to conduct business or organize manufacturing. What they represent are more coherent sets of principles and methods that inspire and guide manufacturing systems design. Paradigms can be useful schemes for identifying knowledge aspects when they are described through a coherent set of criteria. A scheme by Jovane et al. [7] represents a useful framework for capturing knowledge aspects especially related to innovations, what kind of knowledge is relevant, and where to find it. In Table 1 [8] some additional criteria are presented to further elucidate knowledge aspects. Sustainable manufacturing could be seen as a manufacturing paradigm itself, and as a logic development from previous paradigms illustrated in Table 1 [8], but it could also be seen as containing elements of other paradigms such as lean manufacturing.

Table 1. Manufacturing paradigms and knowledge [8]

Aspects		Paradigm			
Field	**Criteria**	**Craft manufacturing**	**Mass manufacturing**	**Lean manufacturing**	**Adaptive manufacturing**
Business model	**Started**	*1850s*	*1910s*	*1980s*	*2000s*
	Customer requirements	*Customized products*	*Low cost products*	*Variety of products*	*Mass customized products*
	Market	*Pull. Very small volume per product*	*Push Demand > Supply Steady demand*	*Push-Pull Supply >Demand Smaller volume per product*	*Pull Globalization,segmentation Fluctiating demand*
Innovations	**Process enabler**	*Electricity Machine tools*	*Moving assembly line and DML*	*FMS Robots Modulized products*	*RMS Information technology*
	Innovation process	*Incremental*	*Linear and radical*	*Incremental and linear*	*Incremental and radical*
Knowledge	**Behaviour**	*Practical oriented (skills Learning by doing)*	*Centralized decisionmaking. Learning by instructions*	*Decentralized decisionmaking. Continuous improvement Learning by doing*	*Decentralized decisionmaking. Knowledge to be applied instantly*
	Knowledge creation	*Tacit knowledge*	*Explicit knowledge*	*Tacit knowledge*	*Tacit and explicit knowledge*
	Knowledge base	*Synthetic*	*Analytical*	*Analytical and Synthetic*	*Analytical and synthetic*
	Knowledge transfer - Challenge	*Externalize knowledge communicating with customers,*	*Internalize knowledge, for practical use*	*Externalize knowledge, making it more explicit*	*Continuously externalize and internalize knowledge*
	Clustering of knowledge	*Close to customers and craftsmen*	*Large units, not necessarily clustered*	*Close to customers and Suppliers / network*	*Less spatially sticky, ICT as enabler for knowledge transfer*

Lean manufacturing [9], and its' focus on waste reduction, are often associated with the eco-efficiency aspects. Over-processing is one of the seven wastes (or Mudas [10]) of lean manufacturing and means adding more value to a product than the customer actually requires (such as painting areas that will never be seen or be exposed to corrosion). Over-processing is perhaps the hardest waste to see and understand [11]. Over-processing is also closely related to quality management, setting the right quality criteria and values (standards).

When focusing on economic aspects of sustainable manufacturing we see that several of the above paradigms could be relevant. This requires that the manufacturing principles are focused on resource efficiency and also where the environmental and social aspects of manufacturing become the premises for strategic, tactical and operational decisions. The point is that what is the most eco-efficient way to manufacture depends on the manufacturing context [12].

2.2 The knowledge dimension

Knowledge has to come from somewhere – or could it just appear from someone or something that 'suddenly sees the light'? This could easily turn out to be a question of existential or religious nature, which is not our focus. In this paper we will see knowledge creation as the process of coupling and sharing knowledge into a bigger whole. Thus the definition by Nonaka and Krogh [13] of organizational knowledge creation appeals to us: Organizational knowledge creation is the process of making available and amplifying knowledge created by individuals as well as crystallizing and connecting it to an organization's knowledge system.

Knowledge transfer/use includes the movement of knowledge from its point of generation or codified form to the point of use. One of the reasons that knowledge is such a difficult concept is because this process is systemic and often discontinuous. Many knowledge cycles are concurrently occurring in businesses. These cycles feed on each other. The interaction of tacit and explicit knowledge is an important dimension in these cycles and described through the knowledge conversion cycle of Nonaka and Takeuchi [14]. How these cycles are or should be working depends on the manufacturing context which is also reflected in the manufacturing paradigm that defines how things are done in a company. Thus, from Table 1 we understand that the challenges related to knowledge differ significantly between craft manufacturing and for example lean manufacturing.

2.3 User experience and product development

There is a common view that companies need to focus on customers and their needs in innovations and product development. However, the various mechanisms and principles, and barriers for capturing customer needs have not been fully investigated [15]. Ulwick [16] found previous innovation practices were ineffective because they were incomplete, overlapping, or unnecessary and argued for "outcome innovation techniques". These techniques links a company's value creation activities to customer-defined metrics. That customers are not necessarily able to express their "real" needs is important for the knowledge creation process for new or improved products.

2.4 The challenge of getting MOL-knowledge

Craft manufacturing is often associated with SME's for example within boatbuilding, while lean manufacturing is often associated with larger companies in for example the automotive sector. Even if the quality is usually very high in craft manufacturing, procedures and standards are often based on experience and are not very explicit. The challenge will often be to capture and use facts, more objective data, for use in product design and process development. Lean manufacturing, on the other hand, is much more fact-oriented and many tools have been developed for use in e.g. continuous improvement and process development.

Knowledge, as a basis for reducing over-processing and ensuring eco-efficiency, is a challenge in most industries and not only for SMEs or in craft manufacturing. This is due to the difficulties to gain knowledge of what are the real quality criteria according to the real use of the products, i.e. Middle of life (MOL) knowledge. The challenge is normally more obvious for SME's as they often have fewer resources to capture and make use of the data. However, SMEs like craft-manufacturers often have an advantage in that they work closely with customers and in that way gain much tacit MOL knowledge. What these companies need is more accurate and explicit data.

3 The ECO-boat MOL project

3.1 Project background

The Norwegian leisure boat industry has through the development program "Arena Leisure Boat" initiated several large projects aiming to improve the standard when it comes to sustainability. One project have focused on recycling while another project has focused on design for manufacturing through modularization, reuse of modules and increased efficiency. To further complete the picture, key actors in the Norwegian leisure boat industry initiated a project focusing on MOL to get better knowledge about the real use of the leisure boats. The driving force was that facts, and not only experience, vague descriptions, or wishes from market surveys etc, were needed for designing the right products and processes. Facts from how boats actually are used were considered a key-element in boat design for setting the right quality criteria and standards in order to reduce over-processing and create more sustainable products. The four year, 7 million Euro, ECO-boat MOL-project was established with financial support from the Norwegian Research Council in 2011.

3.2 The participants and link to ongoing research

Three leading Norwegian boat builders in their respective segments are representing the industry together with a key supplier. Each company has one main case-focus, but participates in the development and progress of the other cases so that the four case-studies together will constitute a whole:

- Marex (project manager) produces boats 21-37 feet in several categories and applications, but mainly larger leisure boats for international and national markets. The Marex case-study is focused on automatic data capture from the boat itself and involves testing sensors and transfer-protocols and structuring of data from the boat itself and how this data can be used in design choices connected to e.g. dimensions and strengths.
- Viknes produce boats for rough conditions at 25-35 feet for international and national markets in the lower and middle speed ranges. The Viknes case-study focuses on capturing data from service-shops, marinas etc and how this data can structured and handled with regards to design solutions and quality standards and requirements. This case also includes the aspects of how to get e.g. service-shops and marinas to cooperate and share service information with the boat-builder and how both the boat-builder and service-shops can create win-win situations.
- Sandvik is a producer that develops boats based on optimized electric propulsion system and environmentally friendly solutions. The Sandvik case study is focused on the development of a new green boat and on how customer and market-data can be used as basis for design concept choices. This includes developing new tools and methods for gathering such data and utilize them in the design-processes.
- ERTEC is as a producer of wind-screens, doors, windows, tanks, etc. to most boat manufacturers in Northern Europe and is a key player in the value chains of Nor-

wegian boat producers. The main focus of the Ertec case is on how to develop resource-efficient and environmentally friendly production processes in the boat-building value-chain. To succeed in a sustainable and social responsibility view, the need to bring in the whole value-chain is paramount.

SINTEF (Trondheim), University of Agder (Grimstad) and Inventas (Kristiansand) are the Norwegian research and development partners in the project. The project is also linked to an Euro-SME project named BOMA where also other European boat builders and research partners contribute to the research fields.

3.3 Hypotheses

ECO-boat MOL has potentially a very high commercial value as the companies will experience radical innovations in knowledge management that will result in new design-/development processes, products, and - production processes. The effect will be products that better meet the real customer requirements and applications. While this may require new and higher quality requirements the main effect is a large reduction in the processing, hence increased resource-efficiency in the production and supply chain. The hypotheses for the effect of the project ECO-boat MOL are the following:

- Improved design processes through better, more formalized and fact-based knowledge in design and development. Theses process can be completed in a much more targeted and effective manner. New systems and principles for the collection and use of facts will contribute to a reduction in resources spent of about 20%, 1,800 hours annually for the boat builder. The same effect applies to the supplier.
- More resource efficient production - reduced material costs. Boat builders are expected to achieve a gain of at least 30% reduction in production costs for some models. This is the resource efficiency from the boats being manufactured according to specific quality criteria with more optimal molding and structural performance for how they are actually used. This will, in addition to the clear requirements for furnishings, equipment level, finish etc, reduce material costs.
- More resource efficient production process - time and energy costs. The companies will to a larger extent be able to standardize and optimize work processes in accordance with clearly defined quality requirements. The processing is reduced with respect to hourly costs and energy consumption. The effect of a more resource-efficient production process provides an estimated cost-saving of 20-30%.

An important part of the project is the development of a "green boat". In this business case the work is broad in terms of capturing the most environmentally optimal product solutions. This entails the hybrid propulsion system, hull-effective solutions, materials, etc. In such a strategy, the fact-based knowledge and methodology developed by ECO-boat MOL will be fundamental. This business case will, in addition to contributions to environmental improvement as a result of the project, have very large potential gains in resource efficiency, helping to strengthen the boat manufacturer's environmental reputation internationally and thus have a market power in an increasingly environmentally focused market for leisure boats.

4 Challenges and solutions

4.1 Basic questions identified and discussed at an early stage

The research is largely focused on how, and to what extent, one can make experience-based knowledge more explicit and factual. The challenges are particularly great for craft-based industries, such as boat manufacturing. This is a question about to what extent one can formalize spread, or experience-based knowledge, and make it available in corporate environments. What are the conditions for customers, workshops and others with knowledge of the boat-usage, to be willing to contribute to knowledge sharing? Presuming that the knowledge and data are available there is no assurance that those who have relevant knowledge can or even will share it. As an illustration, consider a service workshop having important knowledge about how a boat is actually used and its actual capabilities and what service(s) are carried out. Why should they spend time and resources to share this knowledge? To some extent theses type of companies get their income as a result of deficiencies in the design.

Far more important, however, are challenges associated with finding resource-efficient methods to acquire the knowledge from the source / knowledge carrier, structure and then transfer it to the boat manufacturer. Similarly, there are challenges in developing the design and manufacturing processes that make use of the MOL-knowledge in an efficient manner for these kinds of SME's. Business opportunities, but also key research challenges in the ECO-boat MOL project, that has been identified in the case-studies:

- How can leisure boat concepts be developed according to criteria that are sufficiently generic for different global markets.
- How can data of good quality be efficiently acquired in craft manufacturing. This includes new applications and a further development of "the PROMISE" technologies [17], but also how to develop plain (accepted), but good enough, solutions for reporting data from after-sales.
- Process development for definitions of MOL data requirements, analysis and use of data in product design and sustainable production processes.
- Use of the leisure boats under extreme conditions must still be possible and safe. How could this be possible when the boats are designed for a more moderate "average" use. Hence, structural aspects and material technology are important issues.

These research questions have been discussed further with the companies to see how relevant they are for each of them and a roadmap of activities and milestones have been set up to meet these challenges in the project.

4.2 The initial analyses

One of the main activities so far in the project has been to define goals and opportunities for each of the companies based on their specific strategic contexts. Resources and capabilities have been described including SWOT analysis. Table 2 shows excerpts from the SWOT-analysis and illustrates how more MOL-facts could improve the strengths of the companies and help them take advantage of opportunities, but also how such facts could reduce weakness and threats in the business environment.

Table 2. Excerpts from analysis of how more facts could impact SWOT

Strengths (internal view)			**Weakness (internal view)**			**Opportunities (external view)**			**Threats (external view)**		
Production	Design/ product dev.	Sales/ marketing	Production	Design / product dev.	Sales/ marketing	Production	Design/ product dev.	Sales/ marketing	Production	Design/ product dev.	Sales/ marketing
Fact-based improvement and fixed format on proposals. Facts required for verifications Facts and "experience database" for prevention of making the same mistake repeatedly	Structuring of customer feedback. More able to manage information from a wider group of customers Solutions where the customer logs events / status for boats More facts reduces time calculations according to ISO and CE. Better basis data on new materials	2-way solutions for service. Fixed format for reporting service Getting more data from the ERP-system Structured e-mail systems, etc. in own service unit A proper customer app. Accurate measurement tools will enable identification of profitability areas and dependencies	Facts is the basis for the formalization, standards and modulari-zation Better documented and available material facts reduces errors in molding/ manufacturing	Facts reduces risks for knowledge to disappear with people Facts is crucial for quality standards on structure, attributes, services etc. New information reveals desire and need for further. Good, but "scary" as it could "eat capacity"	Facts / data as a basis for pricing. What is important to know about the boat? Are there ghosts (repetitive problems) we need objective information on?	Be able to capture state of the art technology e.g. PLM Facts about the total market in our area, as well as the new markets for our boats / services	The sunbridge revolutionized us, but design was based on subjectivity - what if they where built on facts and more structured market input?	Less focus on the environment today than before? The need for facts to describe and explain environmental aspects Surveys of people boating, requests for services and needs will be able to give us ideas on priority areas..	Automatic data collection from production - systems for benchmarking with other companies and industries Thorough market data help us defining "qualifiers" and "order winners" in different segments	Dealer logg All actions and issues registered. Provides a product story as input to design and improvements Important for product development of the right product today and tomorrow	Provide facts to regulatory bodies, government etc Input to market/ industrial foresights Broader range of customer facts for conceptual-ization, etc. Again, the mapping of people's habits and plans to tell us how the impact will be.

4.3 Where could facts be found – the basic model

We understand that there is a great need for more facts to improve design and production processes in the leisure boat industry (and other industries) to reduce a negative environmental impact of over-processing. But where are these MOL-data and how could the companies be able to retrieve and use them? ECO-boat MOL has identified at least three important sources for the MOL-data.: the boat itself (1), those being in contact with the boat in service, maintenance etc (2), and the customers /market (3).

Through sensors ECO-boat MOL will develop solutions and principles for instrumentation and automatic data collection (1). This will be a source for data about, stress, speed, how often a boat is used, under which weather conditions, noise etc. These data are critical data for identifying quality criteria and setting the standards. The second source of facts is marinas (2), maintenance and other after-sales activities following the boat after it has been sold. All these different functions and people that are in touch with the boat have a lot of knowledge about the real use of it and the strengths/weakness of it. Being able to capture and transfer this knowledge in a "simple" but efficient and structured format could be a strong advantage for the boat builders. Customers' expectations and needs have also to be captured as input for product design (3). This kind of information has often been collected by different kinds of surveys, talking to key customers etc. However, the problem has often been that there have been difficulties to capture how the boats actually are going be used. The project aims to use different technologies for virtual communication to identify different use-concepts.

From these three sources, data have to be collected and transferred and stored in a way that is simple enough for SME's and low-tech companies to deal with, but still at a good enough quality to be useful for the boat builders.

A lot of the work in the project will build on established standards within the marine industry and on the results from the EU-funded PROMISE-project [17]. PROMISE developed Product Embedded Information Devices (PEIDs) with various degrees of processing capabilities – from a basic RFID-tag to a PEID based on RFID with sensors and computational and decision support capabilities. Further, the middleware, communication, and the use of product design knowledge management-databases including decision support in order to filter and handle the large amount of data is also based on a further development and adjustment of PROMISE-technologies. As mentioned in section 3.2, ECO-boat MOL is closely linked to the Euro-SME project BOMA. Together these two projects cooperate to develop the base-technologies and software needed to capture, structure, handle, transfer and use data for item 1 and 2 above. With regard to user experiences, the gathered data will be handled the same way as for item 1 and 2. However, the challenge of actually identifying hard facts on what the customers' need, require or wishes will have to be handled on a nation-wide basis. In this regard, the ECO-boat MOL project aims to develop new tools and methods based on actual user experience and results from the boat industry in Norway. Outcome driven innovation techniques and other tools and methods will then be tested, evaluated and implemented for the participating companies in the project.

5 Conclusion

In this paper we have focused on how reduction in over-processing contributes to sustainability. In the leisure boat industry, as in many other industries, over-processing is to a large extent a result of lack of facts in product design and development. The hypothesis in the ECO-boat MOL project is that over-processing could be reduced by designing boats based on facts of actual use, i.e. MOL-data.

The ECO-boat MOL project need to develop appropriate solutions for capturing and transferring these data. However, to be able to get the desired effect on reduced over-processing, serious work has to be done in the companies involved to design processes where facts are actually the basis for the design and production processes. This is a major challenge in these kinds of craft manufacturing companies characterized by learning by doing, where experience and tacit knowledge are premises in design and production.

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