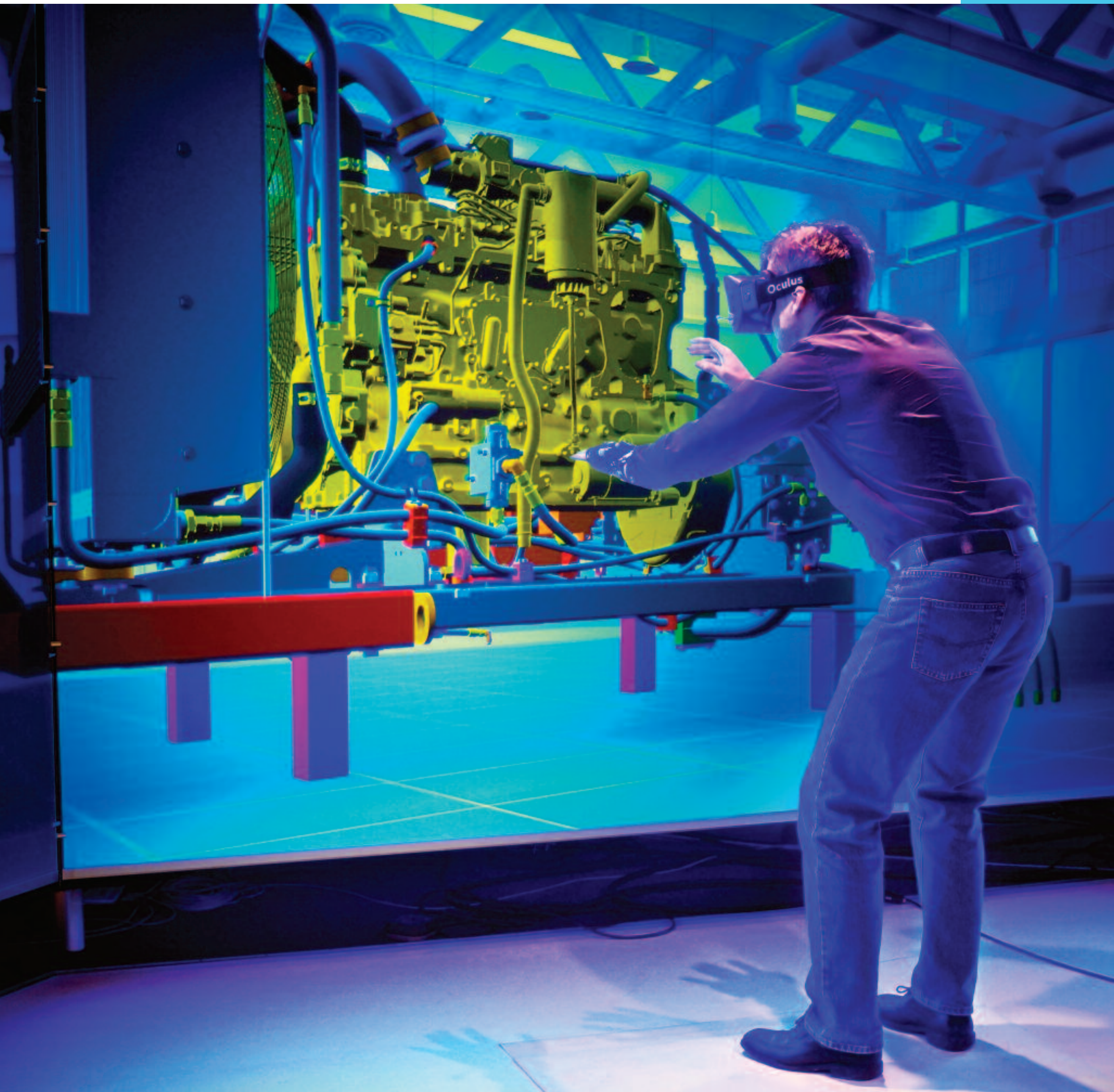
DIMECC

FINAL REPORT 2/2016

DIMECC PUBLICATIONS SERIES NO.10

MANU – Future Digital Manufacturing Technologies and Systems

2012 – 2017



DIMECC

FINAL REPORT 2/2016

DIMECC MANU – Future Digital Manufacturing Technologies and Systems

DIMECC
PUBLICATIONS
SERIES NO.10
2012–2017

Publisher DIMECC Oy
Korkeakoulunkatu 7
33720 Tampere
Finland
www.dimecc.com

ISBN 978-952-238-176-7
ISBN 978-952-238-177-4 (pdf)

DIMECC Publication series

ISSN 2342-2696 (online)

Graphic design and layout: Public Design Oy

Cover image: Jaakko Karjalainen, VTT

English language editor: Semantix Oy

Printed in Finland: Grano Oy, Tampere, 2016

CONTENTS

6 EMERGING TECHNOLOGIES TOWARDS ADDITIVE MANUFACTURING, SUSTAINABILITY AND SMART FACTORY

Nexus of Capabilities

DIMECC's MANU program preparation work was initialized in 2011 with the aim of boosting digitalization in the Finnish manufacturing industry. The preparation work was carried out through intensive co-operation with the leading manufacturing companies and visionary researchers. The program plan, with prioritized activities, was introduced in 2012.

In 2011, our counterparts in Germany had the same kind of initiative on their hands, and the term Industry 4.0 was first used at the Hannover Fair in 2011. In 2012, the working group on Industry 4.0 presented a set of In-dustry 4.0 implementation recommendations to the German federal government.

Today, both of these initiatives are acknowledged as the leading programs in the European Commission's "Digitizing European Industry" initiative. More importantly, however, the importance of digitalization is widely acknowledged within the manufacturing industry, and we can widely see the concrete business benefits behind digitalization-related buzzwords.

These journeys have not been easy ones, but required a nexus of right capabilities, meaning interdisciplinary co-operation among the right experts from industry and research. In both cases, this co-creation has had a strong industry commitment, which has ensured the impact of the results. In addition, the public authorities have supported the work by ensuring an environment for risk-taking and the wide promotion of the importance of digitalization.

I want to warmly thank the whole DIMECC MANU team for their great work in the program. I would especially like to acknowledge the efforts of the program preparation team for their visionary work, the program manager Dr. Kai Syrjälä for his effort in enabling effective co-operation, and Tekes for the funding of this work.

DIMECC MANU's recipe for success, meaning the nexus of necessary capabilities, has shown its effectiveness, and it can also be used in the future. In Finland, we have leading ICT and industry capabilities, and thus an exceptional possibility to lead industrial digitalization on many fronts. If Finland uses the power of co-operation effectively, the Finnish initiatives will also be noted among the world-leading ones in the future. Please keep this in mind while reading this final report and the great results achieved.

Dr. **Kalle Kantola**
CTO
DIMECC Ltd.

Integration of Research and Industry Challenges

DIMECC's MANU program started in 2012, and there our joint digitalization journey also started, with the challenge of tying together the different parts of digital manufacturing value chains. In DIMECC MANU, this meant the coordination of versatile research topics, from welding-related simulations to supply-line development, which had different starting points but common targets. To reach the common targets, various competencies were required, which needed to be managed together effectively.

"Digitalization" as term is a very wide one. In DIMECC MANU, digitalization is understood as updating the top art practices to digital SW tools for fast use and repeatability. Digitalization provides tools for virtual design and production environments (simulations, FEM, 3D-printing), and in the end, configurable products and in production.

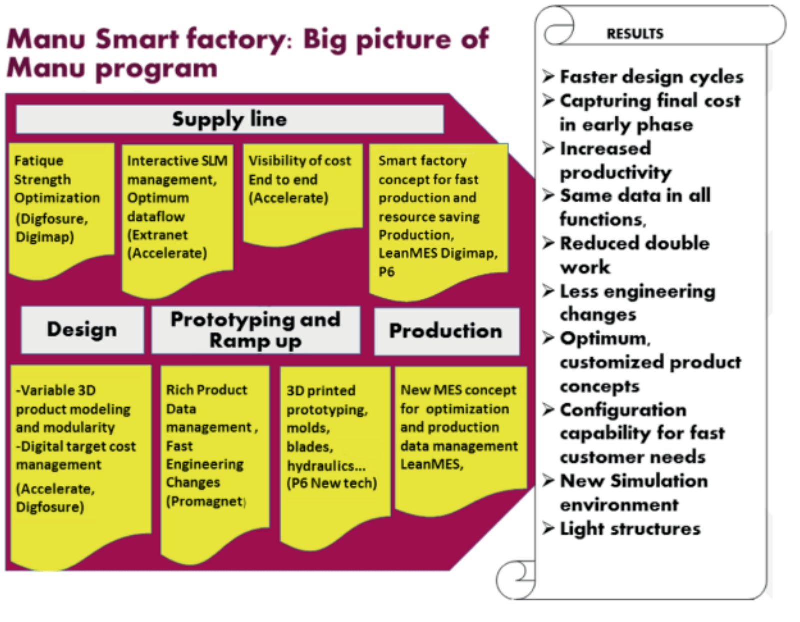


Figure: **Mapping of DIMECC MANU content with interfaces**

From a business point of view, the final goal was to streamline processes for improved productivity. A lot of non-value-adding work like manual "spread-sheet operations" can be discarded, while fewer errors in operations and online visibility inside projects across company borders have been achieved.

In DIMECC MANU, set interfaces (see figure) and ambitious streamlined goals with industry partners were turned into research objectives and new practices. New research results and practices were then transformed into digital form.

The Industry 4.0 initiative has been strongly developed in Germany. However, it cannot be directly applied to Finnish industry. Digital models for optimization of production lines target the fastest break-through times for production. This is a big driver for the car industry as, for example, a 1% cost reduction is meaningful if 60 million brake disks are machined. Finnish industry, however, consists of companies producing highly customized products and project-based machinery deliveries without the benefits of mass production. DIMECC MANU is hitting this issue. We have developed fast supply lines with customized digital software, updated product data management for product ramp-up, effective material flow for components, metal 3D-printing applications for plastic molds, and even copper-based machine components with heat treatments. All of these actions have had one ultimate goal: a novel Smart Factory, which means smart design, effective manufacturing, and agile operations.

Smart Factory thinking and the combination of research results, together with teamwork, have been a success. Workshops in DIMECC MANU companies have created development plans and focused investment plans. A remarkable increase in business has been achieved. The lesson learned is that access to new technology, like robotics, is easily available for Finnish SMEs, but they need to take brave, risky decisions to invest in digitalization. Time is money, also in investment planning!

World-class production technology (welding, CNC milling, assembly, 3D-printing) and full digital product and production definitions for machining in factories are the key drivers for the success of manufacturing businesses. We have examples of the successful progress of companies in DIMECC MANU like Ponsse, Metso Minerals, and Raute, just to mention a few.

However, the digitalization journey is not over, and research in this area needs to be pushed! Short-term implementation in SMEs is important. Several companies have low volumes and low profitability that can be radically improved by digital solutions. Collaboration between research units and SMEs in Finland has turned out to be a success story in DIMECC MANU. SMEs have limited resources for research and digital development.

It has been a pleasure to be in the DIMECC MANU team! DIMECC MANU can share a lot of brand-new research results, more than 100 publications, and a lot of digital applications implemented in DIMECC MANU programs. We have created a foundation for digitalization in Finnish industry. Therefore, I give my warm thanks to all those who have been involved to make DIMECC MANU happen, sincerely.

Dr. **Kai Syrjälä**

DIMECC MANU Program Manager
Senior Consultant
Kaidoc Ltd

Ponsse PLC

It has been a great privilege to participate in the DIMECC MANU program as a representative of one of several Finnish industrial forerunner companies. The program has been a good example of our national capabilities in bringing challenging visions to life as concrete support for daily work in today's global competition. In DIMECC MANU, the vitally important rapid introduction of new ideas and ways of working has been enabled by seamless collaboration between companies, universities, and research institutes. For the participating companies, collaboration has made it possible to tackle more complicated and riskier problems than the companies could have dealt with by themselves. For the participating universities and research institutes, on the other hand, DIMECC MANU has provided a world-class industrial platform on which to test and implement next-generation ideas and solutions in a real-life environment. The quality of the achieved results has further been enhanced through effective cross-learning among the participating companies, as well as among all the implemented projects. DIMECC MANU's concept of accumulating knowledge and know-how has proven to be highly successful.

In DIMECC MANU, digitalization has shown its true value in speeding up processes, as well as in cutting waste and costs through improved excellence in all operations. With modern digital tools, a larger number of realization alternatives can be analyzed before even the smallest part of the product or service has been concretely realized. Among other tools, modeling and simulation, optimization, virtual and augmented reality, and testing have improved the competitive edge of DIMECC MANU participants.

Similarly, modern digital systems bring more knowledge to decision-making. The lessons learned from earlier designs and production can be stored and reused when building solutions according to new customer needs. More silent knowledge can be formulated as guidelines, to be used in design for manufacturing and assembly. This evolution makes the companies less vulnerable to knowledge loss, such as in cases of company acquisitions or personnel arrangements.

This concerns not only the capabilities of the OEM company, but also the capabilities of the whole supply and delivery network. When digitalization is used in an intelligent way, the requirement to make things "first time right" in the whole network can be repeatedly fulfilled. In practice, this is the only possible way to operate profitably.

To keep the competitive edge acquired in DIMECC MANU, the next steps need to be taken promptly. Tomorrow already begins today. Enjoy the journey!

Juho Nummela

President and CEO, DSc (Tech)
Ponsse PLC

VTT Technical Research Centre of Finland Ltd

I had the honor of preparing the DIMECC MANU program together with a working group chaired by director Juhani Rantalainen from Fastems Oy Ab. The task given was to bring together at least 15 companies and several research institutes with the common goal of increasing the competitiveness of the Finnish manufacturing industry by means of digitalization. However, the interest within the industry was even bigger than expected, and the final number of companies participating in DIMECC MANU was more than 30. Several good proposals had to be rejected or cut in volume in order to keep the size of the program within reasonable limits. For research institutes, this high level of interest from industry made working in DIMECC MANU, of course, very motivating. This is certainly one explanation for the high-level results achieved in DIMECC MANU, both from industrial and scientific points of view. DIMECC MANU was an excellent example of a working public–private partnership in research.

The topics of DIMECC MANU covered different aspects of digitalization of manufacturing, including digital tools to manage and optimize manufacturing processes, as well as information flow in manufacturing networks and in manufacturing execution systems. For a researcher, it has been very rewarding to see the research results being demonstrated by or even implemented in industry. Among other achievements, the DIGFOSURE project demonstrated a cell with camera-based automated inspection technology for low-volume, complex geometry welding production. The DigiMAP project developed an optimization tool for the design and manufacture of high-strength steel structures. In ProMaGNet, a good example is a customized product data management (PDM) system that has been brought into industrial use. In the ACCELERATE project, a digital system for the management of the supply line and supplier network has been developed and implemented with good results. The Lean MES project demonstrated LeanMESsenger, a tool for the dynamic allocation of tasks to available and capable workers.

The DIMECC MANU program has had close links to other relevant research initiatives, which has further increased its impact. A good example is the DIGFOSURE project, where a broad researcher exchange with South Korea, in the field of the simulation of welding, has taken place in close co-operation with VTT's FiDiPro project.

An interesting feature in DIMECC MANU has been the Next Generation Manufacturing project, where only research institutes were funded and where the research topics were decided separately for each funding period. This gave, on the one hand, a certain freedom to researchers, and on the other hand the flexibility to react to the fast-changing technology and needs of industry. For the first funding period, the topics chosen were additive manufacturing (AM) or 3D printing, and sustainability performance indicators. AM, in particular, turned out to be an excellent choice, as during DIMECC MANU the printing of metal components developed from a laboratory method to an industrial process. AM remained as a research topic for the whole duration of DIMECC MANU, while sustainability was, in the last funding period, replaced by Smart Factory, which summarized the results of DIMECC MANU in four workshops and in a handbook covering different aspects of the research carried out during the program.

The good co-operation between industry and research institutes that took place in DIMECC MANU will continue within DIMECC and also in other contexts. Several proposals based on DIMECC MANU projects have been submitted or are under planning both at national and at European level. Some may even say that the rise of DIMECC is a continuum of DIMECC MANU, since digitalization has proven to be the primary technology change driver in manufacturing industries.

Pentti Eklund

Principal Scientist,
VTT Technical Research Centre
of Finland Ltd

DIMECC MANU IN A NUTSHELL

Company partners (Pcs.):	35
Research institution partners (Pcs.):	6

Volumes

Duration:	01.10.2012 – 31.12.2016
Budget:	22,2 M€
Company budget:	12,2 M€
Research institution budget:	10,0 M€
People involved	145

Results:

Number of publications: 122

Number of doctoral theses: 7 finished and 6 under work, unfinished by end 2016

Number of other theses: 31

Patents and invention disclosures: wide portfolio inside companies, not shared to consortium

New software products:	5
Research exchange months:	88
New commercial software products	5
Volume of spin-off projects	50 M€
Enabled business potential (estimate):	1 Billion €

PROJECT NAME

DIGFOSURE

P1

Mika Sirén/VTT Ltd
Tero Lokasaari /Wärtsilä Energy Solutions

Digital Manufacture and Fatigue Optimization for Superior Reliability

Summary of the project's motivation and achievements

Background and motivation

There is a clear need to shorten the design and development time spans of new products in the Finnish machinery industry. One way to shorten the time to market or profit is to introduce modern integrated digital design tools to support the machinery industry's product design and development. One area in particular in which this need emerges is the fatigue design of welded machinery structures with a long service life and high structural and operational reliability requirements. The importance of fatigue behavior optimization is further emphasized by recent structural material developments, such as the introduction of novel steel grades, and the related attempts at lightweight machinery solutions. The resulting smaller sheet thickness enables the use of laser-based welding processes for a further productivity increase, but also introduces distinct features in structural behavior.

The manufacturing parameters in the welding process can be optimized according to productivity and quality. The conditions for enhanced productivity can be created with the aid of design, for example by means of optimizing the weld geometry, welding process, position, and accessibility. Quality is proportional to the weld performance in conditions of use. In manufacturing, productivity and quality are not mutually contradictory, and with successful optimization, good quality can be achieved efficiently and profitably. To optimize both productivity and quality simultaneously, the product and production requirements must be properly controlled in such a way that the quality is allocated appropriately to where it is needed, and the features it entails in each particular case are defined.

An answer to the above demands is an integrated simulation and analysis approach covering the entire design chain, from the welding process, resulting in metallurgical properties, weld geometry, residual stresses and distortions, to fatigue strength and eventually the life-cycle characteristics of the welded structure. However, the vast amount of data involved in the above also requires modern data-processing tools to transfer the relevant key data from the design office along the value chain to the (often remote and/or subcontracted) production. In the other direction, reporting the quality control and assurance data, possibly topped with production technology information from the subcontractor shop floor back to the relevant OEM parties (assembly, delivery), and further to service and/or after-sales, is also vital for fluent and efficient production and use.

Modern welding simulation software tools provide the means for calculating accurately the welding deformations and residual stress state resulting from a particular welding procedure. The results can be used further, either as source data for fatigue analysis and design, and/or for optimization of welding procedures and sequences for productive welding fabrication. Coverage and digital processing of the interdependencies between the welding process and parameters and the resulting weld fatigue properties in simulations is a major challenge in the fatigue design and simulation of a welded structure. This requires the discovery and use of the interactions between the welding process and the resulting weld geometry, and further between weld geometrical features and fatigue strength, and eventually use and service-life characteristics.

Project achievements (partner specific)

The main project breakthrough for the marine and shipbuilding industry, including companies such as **Meyer Turku**, was the development at **Aalto University** of the basis for a new fatigue characterization method that is suitable for high-quality weld profile measurements and digital manufacturing. The method is applied to the fatigue strength analysis of laser-hybrid welded joints used in, for example, ship deck structures. This work has novelty, since it is the first time that the real weld geometry on a microscale has been successfully considered directly in the fatigue strength assessment of welded joints.

Using robots in automotive industry production lines is a key contributor to keeping European car manufacturers competitive against the threat caused by cost pressure from Far East manufacturers. Automation is not limited to manufacturing and welding, but quality control is also more and more done automatically using special measurement units. However, the products are complex, and multiple different car types are built on the same production line. There is no additional time to recalibrate the measurement systems or do manual work on moving parts in the quality-checking units. **VTT** and **Mapvision** together developed a robotic control unit, machine vision system, and algorithms to check if the holds, welds, and bolts are exactly in the right place compared to the CAD drawing of the part. The robotic unit was optimized to follow the welding path in the component design and to make the necessary corrections online.

Numerical and analytical methods can be used to predict the quality of welded structures. The aim of the simulation studies at VTT was to evaluate the possibilities to use mathematical methods for welding process optimization. The study also includes evaluation tests related to transferring Sysweld simulation results into other commercial FEA programs, in order to evaluate the effect of residual stresses on fatigue. The tests show that the two programs can be used together to aid optimization of the welding process. The use of numerical methods requires an extensive amount of work and also includes time-consuming heat-source calibration. Although there are programs available on the market that calculate the heat input model automatically, they are usually restricted to specific processes. Even if the use of numerical methods requires extra resources, the work is justified, at least in complicated cases and when quality is the primary concern.

The results show that analytical methods can be used for first estimation of, for example, cooling rates and microstructures in welding. These methods are easy to use and help in the work of specification of optimal welding parameters. They can be used to define first estimates of process parameters for simple welding cases (Figure 1).

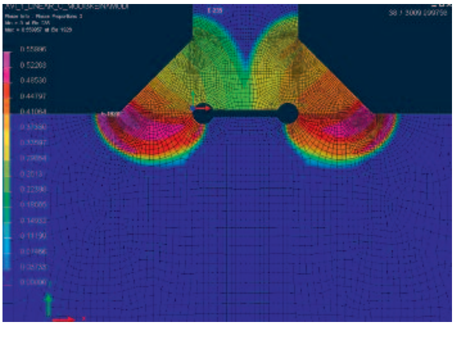


Figure 1. Martensite phase fraction in the arc welded T-joint, calculated using SYSWELD (steel S355J2G3)

One of the main targets set for the program by **Kesla** was to study and determine welding parameters for high-strength steels in forest machinery manufacturing, in collaboration with **LUT**, and to encourage product design and manufacturing co-operation in the case of high-strength steel product manufacturing. The parameter studies were found to be quite successful: critical factors for fatigue durability could be improved by managing and avoiding fatigue cracks, as well as finishing welds, undercuts, and geometries. However, the design aspects were more challenging. It was difficult to manage thin walls without deformations in manufacture. This requires more work on optimizing construction such as wall thickness and welds, design for manufacturing, (robot) welding, machining, assembly, and digitalized document management such as welding specifications, instructions, and feedback.

During this project, Kesla Oyj created design and manufacturing instructions for HSS welding. The stress level of the weld-structured main booms of a crane were measured during field tests. Weld tests were executed in co-operation with material manufacturers. Alternative manufacturing methods for profiles have been taken into account when selecting steel profiles for forest machinery manufacturing. The Master's thesis "Development of the manufacture of a telescopic boom" was made together with LUT.

Figure 2. Novel Kesla UHSS truck crane boom (left) and the final product in operation (right)

For **SSAB**, the purpose of this project was to define relations between alloying of steels, microstructure, and the mechanical properties of the heat-affected zone (HAZ), as well as the used weld metal, and to apply that information in a simulation tool that would estimate the weld mechanical properties based on base material, welding parameters, and the filler material. The steels investigated together with the **University of Oulu** were ultra-high strength steels (UHSS) in strength classes 960 MPa and above. Furthermore, the target was to find out the best alloying combination allowing good toughness properties of HAZ/weld metal and matching weld. The Digfosure project has enabled the design of ultra-high strength steels that have enhanced weldability, and the new data produced within the project has been added to the simulation tool, thus improving its performance.

Data analyses and thermomechanical Gleeble welding simulations have been carried out for the MAG welded project steels (Strenx 1100 MC and S1300) to model different heat-affected zones with different cooling rates. The results show that Strenx 1100 MC and S1300 have excellent toughness in HAZ, and they both fulfilled the 14 J impact value requirement for a specimen of 5 mm with 5 s and 10 s t8/5 times at -40 °C. Gleeble results confirmed this excellent toughness of the project steels. Contrary to toughness in HAZ, both of these welded steels had a significant drop in strength from base metal to HAZ. The reasons are low filler metal strength and softening of HAZ, which is normal at these strength levels.

Additionally, some welding experiments were performed using modern welding methods like laser and laser-MAG hybrid welding, to get information about static and dynamic properties of welds and compare the achieved results to the joints welded with a conventional MAG welding process. In this case, both the matching and under-matching filler materials were used. The results showed that, in this case, fatigue is not dependent on the welding method, but the geometry of weld is the dominant factor.

The **Wärtsilä Energy Solutions** target was to develop scientifically based state-of-the-art engine-generator set steel structure fatigue-dimensioning criteria. Engine sizes and outputs are rising and fatigue design is becoming highly critical in engine-generator set applications. During the project, fatigue tests were carried out at Tampere University of Technology (TUT) for the base frame sub-model, and fatigue dimensioning instructions and a fatigue test device were developed.

The first main results were experimental fatigue tests for a base frame sub-model in the TUT laboratory for S235 and S355 steel grades. Comparison of the experimental and FE analysis results showed that the FE analysis predicts fatigue-critical locations correctly, and fatigue durability can be estimated based on analysis.

The second main achievement was a fatigue dimensioning guideline that enables engine-generator welds to be dimensioned using FE analysis and virtual 3D models. Even measured 3D geometry can be used. Fatigue dimensioning instructions were utilized for the Wärtsilä 18V50SG B-stage engine base frame: the frame design was upgraded and new manufacturing drawings were prepared based on the analysis. Instructions were also utilized successfully, as field repairs were made to the 20V46F at Maracanau power plant in Brazil, which was suffering from fatigue issues.

The third major achievement was an in-house ultra-high cycle test facility developed at the Wärtsilä laboratory. The first preliminary tests have been completed to verify that the test system functions. These tests have already indicated important factors contributing to fatigue durability in the high-cycle fatigue region. Not all the planned tests can be completed during this project. However, the developed fatigue test arrangement gives great possibilities to improve fatigue dimensioning in the future.

Developments in the project have increased fatigue dimensioning know-how greatly and have provided tools for designing new products at a detailed level. This know-how also serves as a great tool for field repairs. The future plan is to develop a new engine-generator set base frame concept based on the improved know-how. Another future step is to utilize the in-house ultra-high cycle test facility for testing, to improve fatigue dimensioning criteria based on test results, and finally to update this expertise in the fatigue dimensioning instructions.

Three different loader boom concept designs were created and evaluated by **Sandvik Mining and Construction**. Lay-out and final design, as well as FEA, were done for these concepts, and three prototype booms were manufactured using different welding methods. A bench test by LUT and field tests were completed, and the results from the FEA, bench test, and field tests were compared. The key results are a 700 kg weight saving (–25%, target –30%) and the targeted life-time achieved for prototypes, but it is not yet possible to show product cost savings (target –20%). However, the new boom concept has reduced the number of parts and the amount of welding measured in kilos.

The Digfosure project work has been carried out in close co-operation with different companies and research institutes: one of the great achievements has been contacts between technical experts in different companies and research institutes through this project. Project management pushed communication toward open sharing, and meetings were even arranged between technical experts, to share their expertise on specific topics.

Key results and impacts

CASE MEYER TURKU: Thin deck structure provides better energy efficiency and increased payload

Ingrit Lillemäe, Sami Liinalampi, Heikki Remes (Aalto),
Antti Itävuo, Ari Niemelä (Meyer Turku)

To build more energy-efficient large steel structures such as cruise ships, new lightweight solutions are needed. Smaller plate thicknesses than the currently considered limit of 5 mm could be utilized in some parts of the structure, if modern production technologies, such as laser-hybrid welding, are utilized. However, the lack of knowledge about fatigue resistance, in addition to buckling, vibration, and manufacturing considerations, is preventing the rules and recommendations from allowing the use of thin plates in large steel structures. The main challenges related to large thin-plate structures are caused by their welding-induced distortions. Due to the low bending stiffness of the plate itself, the distortion shapes and resulting structural behavior are different from thick plates. Therefore, traditional fatigue assessment approaches do not describe the fatigue strength of thin structures accurately. In addition, thin plates are more sensitive to the geometrical properties of the weld and require a more advanced fatigue characterization method. When laser-hybrid welding with properly optimized welding parameters is utilized, reduced initial distortions and smooth weld geometry are possible, resulting in high fatigue strength. However, in order to transfer the fatigue test results to fatigue design, the behavior of a larger thin structure also needs to be understood. In a stiffened panel, considerable distortion occurs in both directions on the plate surface, and in the surrounding plates, stiffeners and girders redistribute the loads.

In this case Meyer Turku, a fundamental understanding of the fatigue behavior of thin deck structures and a technologically feasible solution for thin deck manufacturing was developed. For the first time, the response and fatigue strength of a thin full-scale laser-hybrid welded deck structure under realistic loading, similar to hull girder bending, was studied experimentally and numerically. Both small- and full-scale specimens were cut from the same thin deck panels. The dimensions of the stiffened panel represent a typical ship deck structure, and the weld quality reflects a typical shipyard manufacturing process (see Figure 3). Thin deck panels were produced by Meyer Turku shipyard and Winnova Oy.

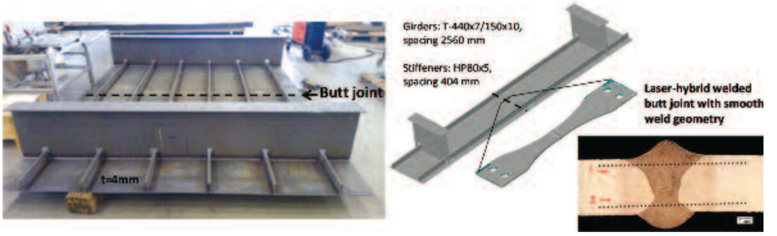


Figure 3. Full-scale thin deck structure, full- and small-scale specimen, and macrograph of a laser-hybrid welded butt joint with smooth weld geometry

Experimental and numerical investigations were carried out by Aalto University, while the University of Oulu supported the weld geometry measurements on a micro-scale. The experiments with thin deck structures included accurate optical geometry measurements and fatigue testing under axial tension loading. The amount of initial distortion near the fatigue-critical butt joint was up to 4 times smaller than previously reported for thin arc-welded navy vessel panels. However, even if the distortion is small, the shape still has a significant influence on the structural stress. The measured distortion shapes were applied to finite element (FE) models, and a geometrically nonlinear analysis was performed to calculate the stresses and strains. The results revealed that when initial distortion and geometrical nonlinearity are properly considered, the FE results agree very well with the experiments (see Figure 4), which is rare for full-scale tests. In addition, the fatigue strength in terms of structural hot-spot stress is on the same level for both full-and small-scale specimens, the scatter is low, and the SN curve slope is close to m = 5 (see Figure 5). The measured fatigue strength is considerably higher than the IIW structural stress design curve, indicating that high fatigue strength is achievable in full-scale structures when manufacturing and weld quality is high.

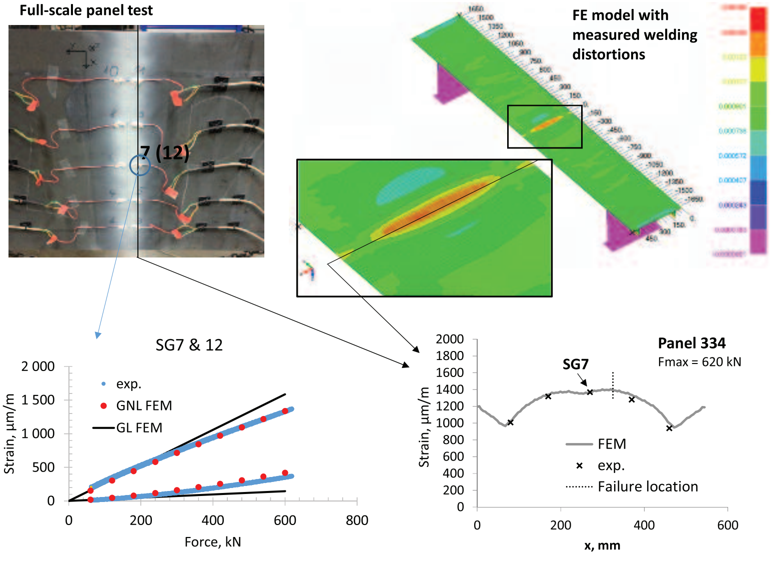


Figure 4. Normal strain from FE analysis and experiments on the fatigue-critical side of the weld

The successful panel test and numerical analysis, completed in the DIMECC MANU project, is a crucial step in long-term development work for thin ship structures (see Figure 6). The previous EU-funded BESST project provided an understanding of the fatigue strength of welded joints, to define requirements for good-quality welding. This knowledge is utilized in this project and thereby will provide an understanding of the fatigue behavior of a full-scale structure, which is a starting point for the next step, to build a prototype block structure in a new TEKES project. This is necessary before the final application becomes feasible for an actual cruise ship. The goal for the implementation of the final application in a cruise ship is about 2025.

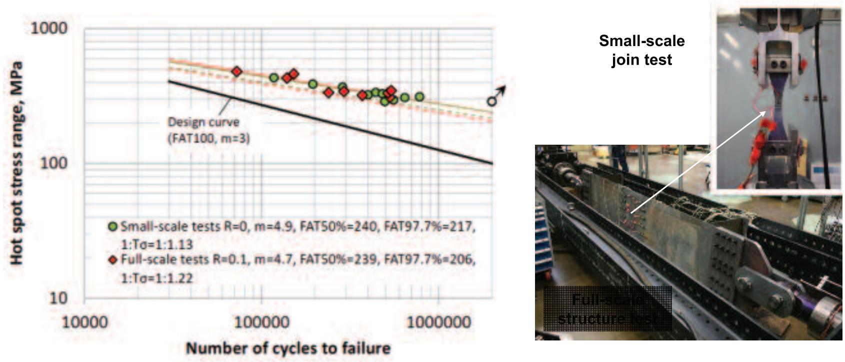


Figure 5. **Fatigue test results in terms of structural hot-spot stress range**

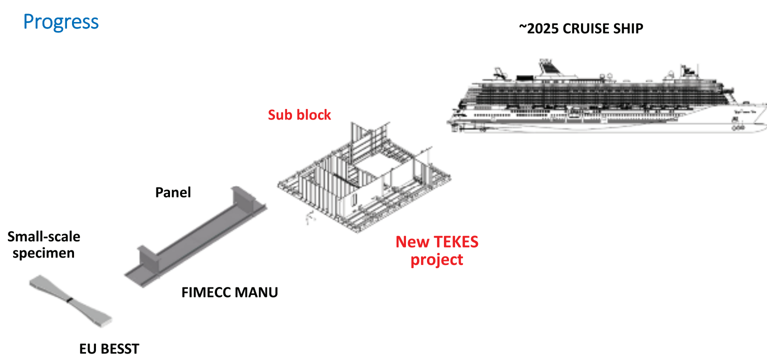


Figure 6. **Progress of research and development work for thin deck ship structures, from welded joints to final product**

RELATED KEY PUBLICATIONS:

Lillemäe, I. Fatigue assessment of thin superstructure decks, Doctoral dissertation, Aalto University, 2014

Lillemäe, I.; Remes, H.; Liinalampi, S.; Avi, E.; Romanoff, J. Influence of welding distortion on the structural stress in thin deck panels, PRADS 2016, 4–8 September 2016, Copenhagen, Denmark.

Lillemäe, I, Liinalampi, S, Remes, H, Itävuo, A, Niemelä, A. Fatigue strength of thin laser-hybrid welded full-scale deck structure, submitted to International Journal of Fatigue in August 2016.

Liinalampi, S, Remes, H, Lehto, P, Lillemäe, I, Romanoff, J, Porter, D. Fatigue strength analysis of laser-hybrid welds in thin plate considering weld geometry in microscale, International Journal of Fatigue, 2016; 87: 143–152.

Lillemäe, I, Remes, H, Liinalampi, Itävuo, A. Influence of weld quality on the fatigue strength of thin normal and high strength steel butt joints. Welding in the World, 2016; 60:731–740.

CASE MAPVISION: Robot welding unit with full digital measurement data

Antti Knuuttila, Matti Kutila

Tolerance in automotive parts varies in different parts of the components. The bolt holes need to be in the right place with a better than 1 mm accuracy. However, the component dimensions may allow more than 5 mm variations without causing rejection. This directly influences the welding accuracy of the components, to ensure that welding follows the designed track within sub-pixel accuracy (see Figure 7). An innovative robot welding unit with full digital measurement data was developed under the DIMECC MANU program. The developed solution brings the quality checking of weld profiles in automated production systems into the digital era, creating prerequisites for high productivity and quality welded structure manufacturing.

Almost all fabrication of metal structures today involves welding. Fatigue is a major cause of failure, especially in welded structures, reflecting the fatigue performance of welded joints. Whether welding together a few relatively simple parts or fabricating large, complex structures, weld fatigue is one of the most common failure modes if the part or structure is subjected to fluctuating stresses. Therefore, the quality of welds is a top priority for manufacturers, especially in the automotive industry.

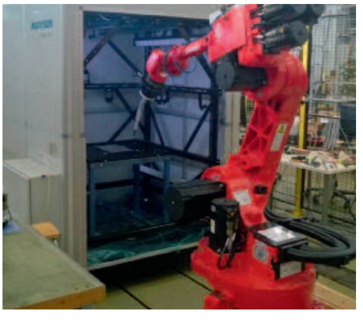


Figure 7. Mapvision quality gate and the robot cell working in a VTT laboratory

A robot welding unit tackling the challenges of weld quality was developed in the DIMECC MANU program. In the solution, the robotic control unit, harnessed with a machine vision system and algorithms, checks if the welds, holds, bolts, and other structural details are exactly in the right place compared to the CAD drawing of the part. There is an adaptive feedback loop from the control unit to the robot welding unit, and necessary corrections can be made online.

The developed solution brings the quality control of weld profiles in automated production systems into the digital era. The solution enables adaptive correction of the welding parameters (e.g. corrections in welding path or parameters) to realize a weld with the desired geometry to fulfil the high quality and fatigue strength requirements. Current solutions just check the component, and if there is a welding failure, the component is rejected. This causes a huge number of material and production losses.

An automated operator-free robot welding solution also improves significantly the efficiency of production lines, offering a competitive advantage to the Finnish manufacturing industry. For example, in the automotive industry, which is one of the target segments of the developed solution, robotization is a key contributor in keeping European car manufacturers competitive against the threat caused by cost pressure coming from the Far East. In addition to manufacturing, quality control also has to be done automatically by a special measurement unit. The products are complex and multiple different car types are built on the same production line. There is no additional time to recalibrate the measurement systems or to do manual work to move parts to the quality-checking units. Therefore, automated quality control and inspection systems are needed.

The solution creates prerequisites for high productivity and quality welded structure manufacturing. The benefits of the developed solution can be counted in savings in material and production losses, and improved productivity. Automated quality assurance in the automotive industry has a significant impact by reducing the risk of calling back cars due to failures in suspension systems. In the case of call-back cases, the losses are counted in tens of millions euros.

Quality is proportional to the weld performance in the conditions of use. With the developed solution, the resulting product service properties can be ensured reliably and accurately. As a result, costs arising from poor quality, such as reclaim, scrap, and downtime costs, can be minimized. For Mapvision, the manufacturer of the online visual inspection solution, this means an additional competition factor in automotive production line bidding.

CASE SANDVIK MINING AND CONSTRUCTION: Speeding up the new product development process with digital fatigue strength simulation tools

Arto Vento, Jarkko Laine

There is a need to shorten the design and development time-spans of new products in the Finnish machinery industry. One way to shorten the time to market is to introduce modern integrated digital design tools to support the machinery industry's product design and development. As a result of the development work done under the DIMECC MANU program, new digital fatigue strength verification methods and concepts were developed.

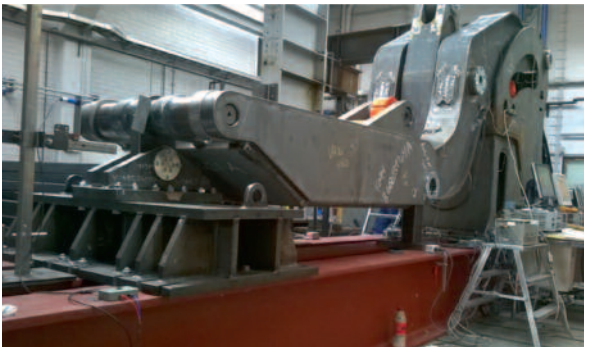


Figure 8. **Fatigue test of the boom structure in laboratory of Steel Structures at LUT and simulation model for the same structure**

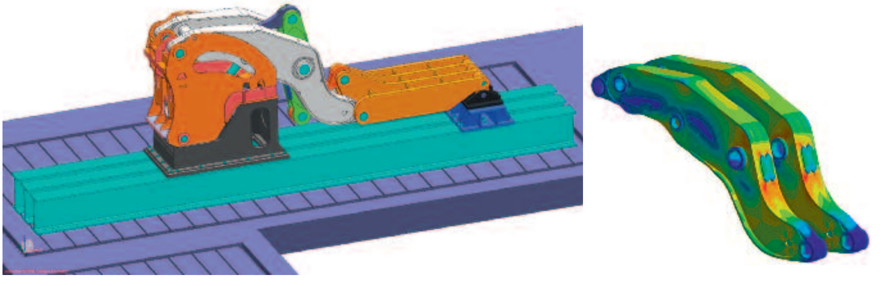


Figure 9. **Simulation and FE-model for the tested boom structure**

An area where the need for integrated digital design tools emerges particularly is the fatigue design of welded machinery structures with a long service life and high structural and operational reliability requirements. An understanding of the fatigue of welded structures is especially important in the case of novel high-strength steel grades, as advanced high-strength steels would bring significant benefits for machinery in terms of lighter and harder structures. But at the same time they present challenges for welding processes. As a result of the development work done in the DIMECC MANU program, new digital fatigue strength verification tools for welds were developed.

In the DIMECC MANU program, a new boom structure utilizing high-strength steel and new welding methods was designed. The successful introduction of a high-strength steel material into a boom structure enabled lighter, stronger, and more efficient equipment with higher payloads and lower fuel consumption. Lightweight boom construction, using high-strength steel material, enormously reduced the structural dead weight and increased the lift capacities. The total weight saving was 700 kg, which is 25% of the boom structure mass. The new boom structure has also reduced the number of parts, resulting in fewer welding kilos and improved robot weldability, which decreases the overall production costs.

As part of the new boom structure development, new digital fatigue strength verification tools for fatigue-critical welded structures, based on the identification of true weld quality, were developed. FE modeling and crack analyses for welds, as part of the component's physically accelerated fatigue testing, was done in order to model the mechanical properties of the welded joints of the high-strength steels. A comparison of FEM predicted fracture initiation locations (see Figures 8 and 9) and true fatigue failure locations based on fracture surface analysis, verifying that the new fatigue stress simulation tools work and the results converge with the outcome from a very heavy testing program.

Modern integrated digital design tools, such as developed fatigue stress simulation methods, shorten the design and development timespans of new products, and offer new tools for designers, increasing the competitiveness of the Finnish machinery industry. The role of modern integrated digital design tools is especially important in the fatigue design of welded machinery structures with a long service life and high structural and operational reliability requirements.

The importance of fatigue behavior optimization is further emphasized by recent structural material developments, such as the introduction of novel high-strength steel grades, and the related attempts at lightweight machinery solutions. Rising fuel prices and environmental issues combined to push machine manufacturers to develop lightweight machines. Novel high-strength steel grades allow these goals to be met in an economically feasible manner. However, high-strength steel presents challenges to welding processes. In order to deploy the benefits of the recent structural material developments, digital fatigue stress simulation tools for fatigue-critical welded structures are needed. Digital fatigue strength simulation methods reduce the time-consuming and expensive fatigue stress test programs, supporting new product development and enabling the testing of new product features.

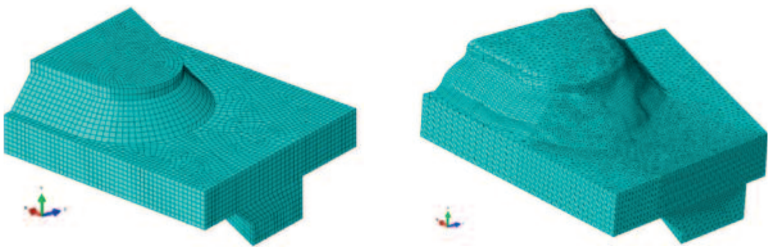
The development work done in the DIMECC MANU program enabled the development of new fatigue stress simulation tools for fatigue-critical welded structures. Furthermore, the methods developed were verified and, according to the results, the model converges with the outcome from a very heavy testing program.

Full digital fatigue strength simulation tools provide one potential way to speed up R&D cycles and shorten the time-to-market. Moreover, solid modeling provides a novel way to analyze product versions for final selection and aids in the development of new products with greater operational flexibility and lower production costs. The new methods may be further utilized, for example, in Sandvik's new product development process.

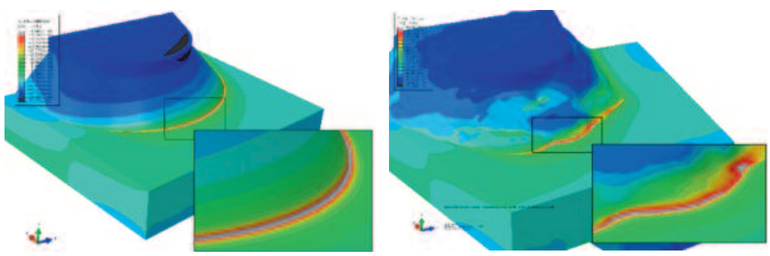
CASE SANDVIK: Comparison the notch stresses between idealized and true weld shapes

Antti Raskinen, Timo Björk

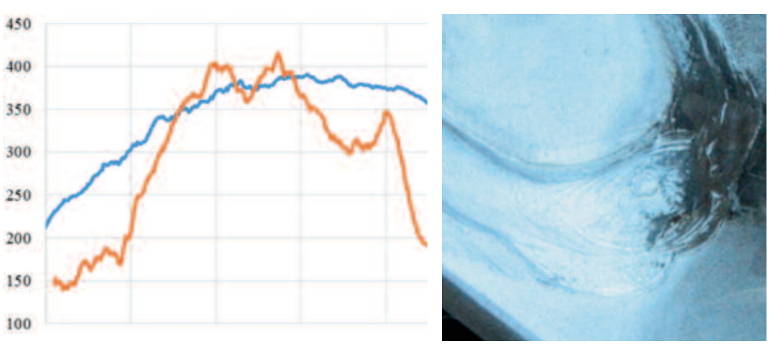
The comparison between idealized and true weld geometry was carried out in terms of ENS (effective notch stress) method. The analyzed cover plate is a part of the boom structure presented in previous case Sandvik. The results from analyses carried out by Antti Raskinen at LUT are shown in Figure 10.



(a)



(b)



(c)

Figure 10.
(a) Idealized (left) and true (right) FE-model of the detail
(b) ENS stresses
(c) ENS stress distribution at weld toe and the 3D model from the measured joint detail

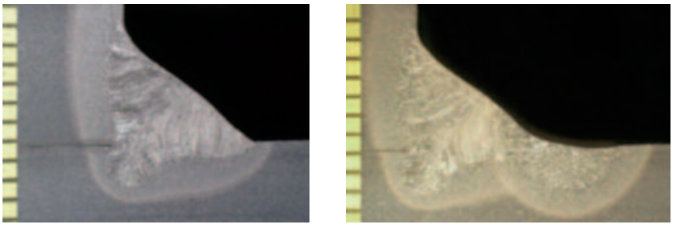
As illustrated in Figure 10 c), the differences between ENS-values are rather small when comparing the idealized and true geometries of the weld toe. The reason for this result is that the radius included in ENS method dominates the notch stresses and the surrounding geometry has just minor effect. This is important result involving in the future efforts to take the local geometry into consideration more precisely in order to improve the accuracy of analysis.

Overall, considerable benefits will be gained through the shortened time-to-market and the more precise design, leading to savings in material resource usage and production efforts during manufacture, as well as more economical operating costs throughout the product service life. In addition, failure avoidance through improved fatigue design, and the resulting safe and uninterrupted operation, decreases the product life-cycle costs even further.

CASE LUT: Post-weld improvement of S960 fillet weld joints by TIG-dressing

Tuomas Skriko, Timo Björk

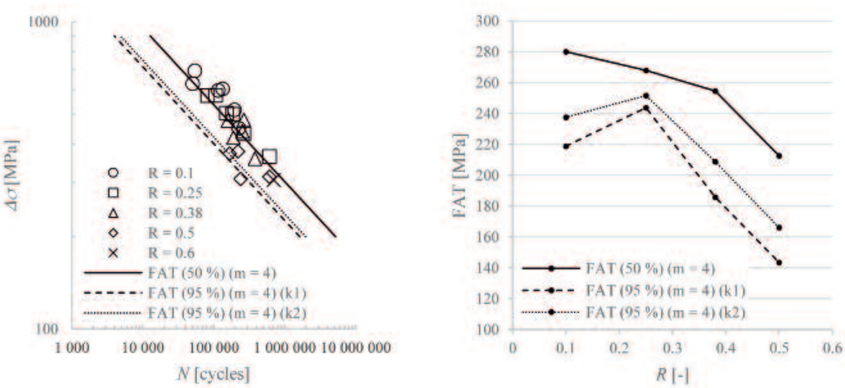
Increased fatigue strength can be achieved when post-weld treatments are applied to welded structures. Generally, post-weld treatments can be divided into two main groups: methods for modification of the weld profile (machining or grinding and TIG, plasma or laser dressing) and methods for modification of the residual stress state (hammer peening, overstressing and stress relieving). The local geometry of the weld toe can be modified by TIG-dressing (Figure 11), i.e. by improving the weld toe shape and removing slag inclusions and undercuts that can act as initial cracks. The foregoing factors will essentially increase fatigue strength and thus improve the quality of the welded structure.



(a) (b)

Figure 11. **S960 fillet weld (a) before and (b) after TIG-dressing**

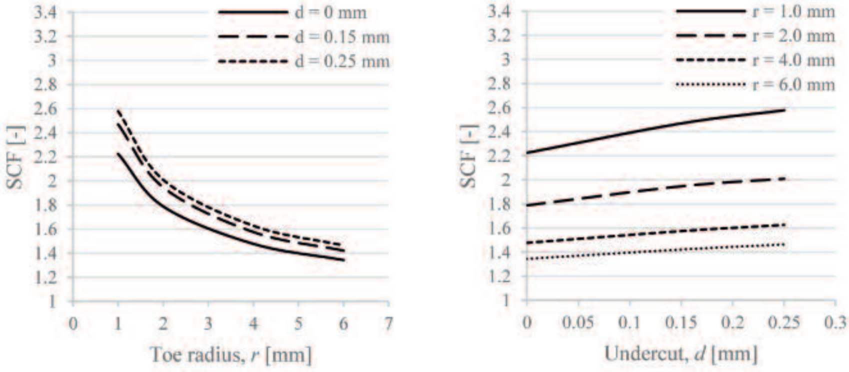
In this study, the fatigue strength of TIG-dressed S960 fillet weld joints at different stress ratios was determined by experimental testing, and statistical analysis was applied to local geometric factors and variables of manually TIG-dressed fillet welds. In addition, finite element analysis with an idealized weld profile shape was used to model and analyze the effect of different joint geometries on the stress concentration factor. A non-load-carrying cruciform joint was used in order to avoid root side fatigue, and a robotized gas metal arc welding (GMAW) process was used to weld the fatigue test specimens and the TIG-dressing was done manually for all the post-weld treated joints. The fatigue tests were carried out under constant amplitude cyclic loading but the stress ratio, R, stress range, $\Delta\sigma$, and maximum stress level, σ_{max}, varied between different test specimens. In every fatigue test, the load and displacement values were monitored from the test rig and strain gauges were used to define the structural stresses and structural stress concentration factors of each cruciform joint.



(a) (b)

Figure 12. Experimental (a) fatigue test results of all TIG-dressed specimens and (b) FAT values as a function of stress ratio

The experimental fatigue tests clearly showed the effect of stress ratio on the fatigue strength of TIG-dressed ultra-high-strength steel fillet weld joints (Figure 12). The fatigue resistance was seen to decrease with increasing stress ratio. The characteristic FAT value was reduced by 30 % when the applied stress ratio was increased from R = 0.1 to R ≥ 0.5. However, the International Institute of Welding (IIW) recommendations, which apply up to 900 MPa yield strength, for TIG-dressing improvement effects on FAT classes were found to be too conservative for S960 grade steel fillet weld joints. Statistical analysis of the geometric variations in the TIG-dressed fillet weld joints showed that compared to the as-welded condition the great change was in the weld toe radius. After TIG-dressing, a major part of the weld toe radii were between 3.0 – 5.0 mm, whereas the radii were below 2.0 mm the in the as-welded condition. In addition, a majority of the joints were without any undercut or the undercut was very small. When considering these geometric factors, the finite element analyses showed that the toe radius and undercut have a significant effect on the stress concentration factor of the TIG-dressed fillet weld joints (Figure 13). A smaller toe radius with deeper undercut will produce higher stress concentration than a large toe radius without any undercut, which is consistent with general theories from the literature.



(a) (b)

Figure 13. Effect of (a) toe radius and (b) undercut on stress concentration factor (SCF)

Further information

CONTACT PERSONS:

The project's primary contact persons are the project manager, Mr Mika Sirén of VTT Ltd, and the industrial chairman of the project steering group, Mr Tero Lokasaari of Wärtsilä Energy Solutions.

PARTICIPANTS:

Wärtsilä Energy Solutions, Meyer Turku Shipyard Oy, SSAB Europe Oy, ABB, Motors and Generators, Sandvik Mining and Construction, Mantsinen Oy, HT-laser Oy, Kesla Oyj, Mapvision Oy, VTT Technical Research Centre of Finland Ltd, Lappeenranta University of Technology, Aalto University, University of Oulu

PROJECT DURATION:

2012–2016

PROJECT VALUE (EUR):

€4.741m

Results

KEY PUBLICATIONS:

Lillemäe, I, Liinalampi, S, Remes, H, Itävuo, A, Niemelä, A. Fatigue strength of a thin laser-hybrid welded full-scale deck structure, submitted to International Journal of Fatigue in August 2016.

Liinalampi, S., Remes, H., Lehto, P., Lillemäe, I., Romanoff, J., Porter D. Fatigue strength analysis of laser-hybrid welds in thin plate considering weld geometry in microscale. International Journal of Fatigue, 2016; 87: 143–152.

Lillemäe, I, Remes, H, Liinalampi, S, Itävuo, A. Influence of weld quality on the fatigue strength of thin normal and high strength steel butt joints. Welding in the World, 2016; 60:731–740.

Björk T, Ahola A, Nykänen T. "Punching shear capacity of T-joint made of high-strength steel". Welding in the World, vol. 60(2), pp. 315–326, 2016. doi: 10.1007/s40194-015-0292-6.

Amraei M, Dabiri M, Björk T, Skriko T. "Effects of workshop fabrication processes on the deformation capacity of S960 ultra-high strength steel". Journal of Manufacturing Science and Engineering, vol. 138(12), 13 p., 2016. doi: 10.1115/1.4033930.

Siltanen J, Skriko T, Björk T. "Effect of the welding process and filler material on the fatigue behavior of 960 MPa structural steel at a butt joint configuration". Journal of Laser Applications, vol. 28(2), pp. 1–9, 2016. doi: 10.2351/1.4943993.

NUMBER OF PUBLICATIONS: 9

THESES:

Ingrit Lillemäe, Fatigue strength assessment of thin stiffened plate structures. Doctoral dissertation, Aalto University School of Engineering, 2014 (partially funded by Digfosure).

Sami Liinalampi, Influence of geometrical variation on the fatigue strength of laser-hybrid welded joints. Master's thesis, Aalto University School of Engineering, 2014.

Sami Liinalampi, Fatigue strength assessment of laser-hybrid welded joints in thin plate structures. Doctoral dissertation, Aalto University School of Engineering, ongoing (partially funded by Digfosure).

Mikko Mutanen, Teleskooppipuomin valmistuksen kehittäminen (Development of the manufacture of a telescopic boom). Master's thesis, Lappeenranta University of Technology, 2015.

Antti Raskinen, Digitaalisen valmistuksen vaikutus hitsatun rakenteen väsymiskestävyyteen (The effect of digital manufacture on the fatigue strength of a welded structure). Master's thesis, Lappeenranta University of Technology, 2015.

Behzad Barzin, Simulation and material calibration of ultra high strength steel (UHSS) S960 welded joint under static tensile test utilizing finite element method (FEM). Master's thesis, Lappeenranta University of Technology, 2015 (partially funded by Digfosure).

Mohsen Amraei, Effects of Fabrication Processes on the Behavior of S960 Ultra High Strength Steel (UHSS). Master's thesis, Lappeenranta University of Technology, 2015 (partially funded by Digfosure).

Lauri Lehtoviita, Ultralujan teräksen kaarijuotto (Arc brazing of ultra high strength steel). Master's thesis, Lappeenranta University of Technology, 2016 (partially funded by Digfosure).

PROJECT NAME

DIGIMAP

P2

Jukka Siltanen, Vili Kesti/SSAB
Anna-Maija Arola, Jaakko Haapio, Kauko Lappalainen, Jari Larkiola/UO
Markku Heinisuo, Teemu Tiainen, Jouko Kiviö/TUT
Ilkka Sorsa/Ruukki Construction
Paavo Hopponen/Kesla
Sami Niemeläinen/Katsa

Future Digitalization Solutions for Effective Industrial Value Chain

Summary of the project's motivation and achievements

The amount of digital information has increased hugely during recent years/decades. However, the usability of this information has not reached the same level. Especially, in the industry, the use of all manufacturing and management information and digital data is important for optimizing and increasing (development of) the production efficiency to the next/higher level. A lot of systems exists like Product Lifecycle Management concept (PLM), Product and portfolio management (PPM), Manufacturing process management (MPM) and Product Data Management (PDM) for digital information handling. However, there is still a lot of manual work needed for updating all relevant inputs. The aim of the Digimap has been to develop a concept that allows information gathered from various sources during the manufacturing processes to be represented in digital form and thus enables to use that information for process design and manufacturing purposes. Research is concentrated on Manufacturing Process Management (MPM) taken into account several industrial environments.

Following companies; SSAB, Ruukki Construction, Kesla and Katsa has been involved in project together with research groups from universities and institutes. Project was divided in three main tasks:

1. Optimization platform for manufacturing of high strength steel structures
2. Development of a Web-based engineering manual of manufacturability (DFM digital data sheets) for high strength steels (HSS) and
3. Development of digital manufacturing management.

The object of the first task was to find rules and instructions for utilizing HS-steels in different structural components. Bending is the most used workshop forming process for ultra-high strength steels (UHSS). The risk for bending failures increases with the increasing strength of the steels. Main achievement was to increase bendability by changes in the steel manufacturing process. Higher work hardening capability on the surface layers of the steel sheet improves bendability. The development of MILP (mixed-integer linear program) formulation for the optimization of HSS frames was another goal of this task. Now, the solution of the cost optimization problem of HSS frames has been implemented to the industrial application (Ruukki/SSAB Design Tool) and real projects have been completed using HSS in normal steel structures which imply the economic benefits of these solutions. Partners in Task 1 were SSAB, Ruukki Construction, University of Oulu (UO), Tampere University of Technology (TUT) and Hämeen ammattikorkeakoulu (HAMK).

The main object of the Task 2 "Development of a Web-based engineering manual of manufacturability (DFM digital data sheets) for high strength steels (HSS)" was to improve machine tool energy efficiency. In addition, the aim was also to give a tool for Finnish manufacturing companies to benefit green manufacturing for increasing competitiveness. Main achievement was a method which differentiates machine tool and machining process efficiency. Utilizing this system SMEs can evaluate their current machine tool energy efficiency properties and show their stake holders their machine tool energy efficiency level. Research in Task 2 was mainly done by TUT and utilized by Kesla Oyj. During this project Kesla Oyj have executed a significant machine tool investment and got it up and running in order to increase manufacturing productivity and capacity for high strength steel booms of the cranes.

One of the main achievement in Task 3 "Development of digital manufacturing management" was attained in Katsa Oy. The production efficiency was increased strongly by optimized factory layouts and new milling technology. Research was done together with TUT.

Key results and impacts

Optimization platform for manufacturing of high strength steel structures

Bending is the most used workshop process to form ultra-high strength steels (UHSS).The target was to develop a material model for ultra-high strength steel bend process. With validated simulation it's possible to understand which factors are affecting the bendability from steel development point of view and how to optimize bending process in the workshop. During bending the outer surface of the sheet is significantly stretched and within this project it was discovered how much the bending tools are affecting to strains. The bigger the strain the bigger the risk for bending failures. It was found that bending radius has remarkable effect on strains and bending angle affect only if the used radius is too small. With these results it's easy to explain to customers why certain minimum guaranteed bending radius is given by the steel supplier. This data was also used to validate the bending simulations. It was found that the CDM- model proposed by Lemaitre describes the material behaviour in bending very well and the simulation results were in good agreement with the experimental results. The localization and shear band development was also modelled.

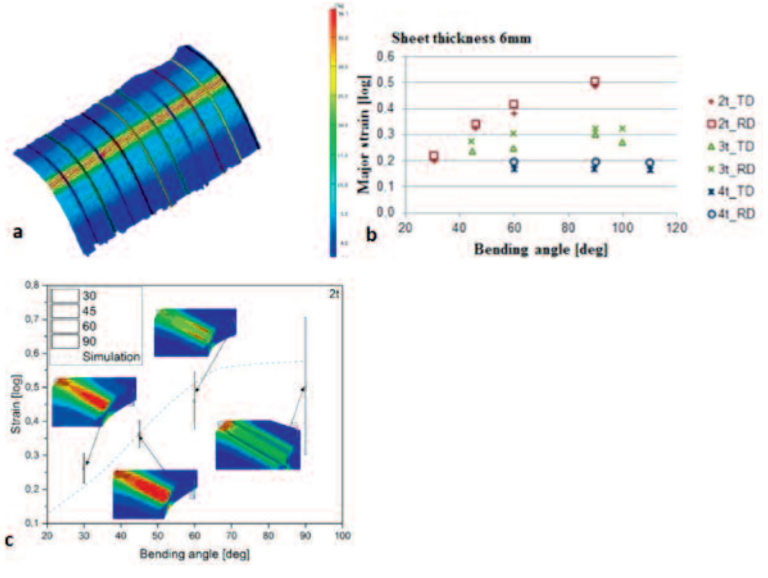


Figure 1. Optical strain measurement of bend surface (a), maximum strain with different bending parameters (b) and simulated strains vs. measured strains with different bending angles (c)

The surface properties of the steel sheet have big impact on the bendability and therefore it's important optimize the mechanical properties of the surface layers.In order to improve the bendability it's vital to have good work hardening capability on the surface layers of the steel sheet. This is very important information from the steel development point of view as now it's possible to concentrate on correct factors and produce UHS steels with better bendability.

Modelling and structural analysis of HSS frames and joints focused on the development of MILP (mixed-integer linear program) formulations. The key result is the new formulation for the optimization of HSS frames enabling to get the global optimal solution. The solution of the cost optimization problem of HSS frames has been implemented to the industrial application (Ruukki/SSAB Design Tool). First real projects have been completed using HSS in normal steel structures which imply the economic benefits of these solutions. The basic research which has been completed for the formulation of the optimization problems and for the surrogate models will enable the design of new HSS structures based on the firm basis dealing with methods and relevant data which is needed in the optimization.

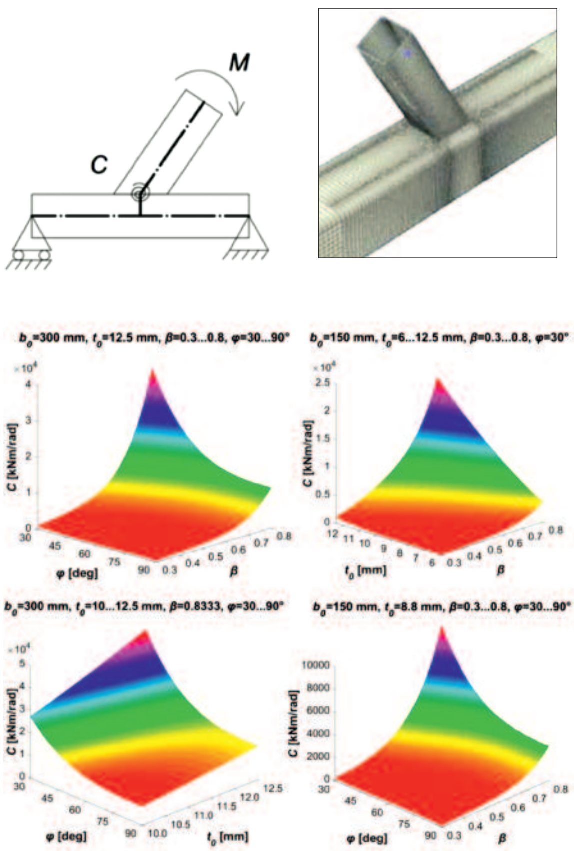


Figure 2. **Surrogate model of initial rotational stiffness C of welded tubular joint**

It has been proven in the project that our roadmap towards cost and environmental effective HSS structures means a large potential for the Finnish fabricators of steel structures, not only for machines, but for the construction sector, as well. Optimization in the design phase including the most relevant data of costs and structural behaviour are the key components of this foundation. Equally important foundation was the importance of standardization of the work processes not only from the point of view to manage the costs but the digitalization and continuous improvement (Lean) of the processes as well. It has been proven too, that digitalization and robotization of (low serial) truss manufacturing make it almost insensible to operator costs.

Machine tool energy efficiency and hard machining

One object the research was to develop a machine tool energy efficiency measurement method, which is suitable for Finnish SME machining companies. The method aim was to give tool for Finnish manufacturing companies to benefit green manufacturing for increasing competitiveness. Besides of useable cutting parameters surface properties of workpieces play very important role in hard machining. One key motivation is to simplify production processes and make them more flexible by substituting grinding with hard machining. In that sense especially surface roughness, -hardness and residual stresses are in a key role when evaluating the applicability of hard machining.

A simple method for evaluating machine tool energy efficiency for SME's was developed and tested. It is possible to use the method at shop floor level. The Method differentiates machine tool and machining process efficiency. SMEs can evaluate their current machine tool energy efficiency properties and show their stake holders their machine tool energy efficiency level. This method also gives companies possibilities to evaluate their current machine tools and energy consumption impacts of upcoming investments and make possible to use current machine tools for more energy efficient way. Companies see that the manufacturing process energy efficiency is important aspect in the future.

Up to now useable cutting parameters and tools have been defined by several cutting tests. These results can be utilized directly in shop floor level to select parameters which are both usable and right to achieve required surface properties and to avoid negative properties which will be lead to early breakage of parts.

Kesla Oyj have executed a significant machine tool investment and got it up and running in order to increase manufacturing productivity and capacity for high strength steel booms of the cranes. Kesla Oyj have got optimized and standardized manufacturing parameters of milling, drilling and boring with HSS material. The level of automation and productivity was increased by developing clamping systems that enables external set up while machine is running.

Katsa Oy has increased their production efficiency by utilizing different digital manufacturing management processes. One main object was to minimize slow grinding operations and even replaced it by machining. Thus, delivery time and costs could be decreased considerably. Machine investment and process parameters for hard machining were defined by exploiting Six sigma (DMAIC-software) with DOE (design of experiments). Experiments were analysed by Minitab optimising tool and the result was a new efficient production method for desired component.

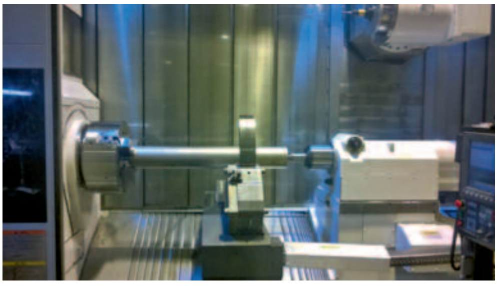


Figure 3a. **Starting of the machining test**

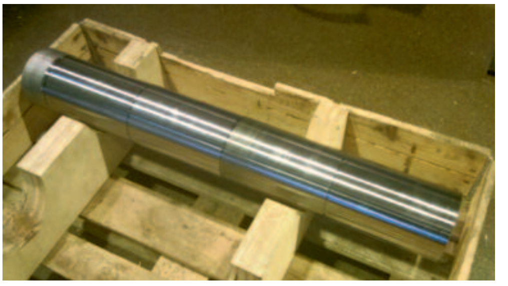


Figure 3b. **Four different areas after machining (testing of process parameters)**

Further information

Optimization platform for manufacturing of high strength steel structures

CONTACT PERSONS: Jukka Siltanen (SSAB), Vili Kesti (SSAB), Anna-Maija Arola (UO), Jaakko Haapio (UO), Kauko Lappalainen (UO), Jari Larkiola (UO), Markku Heinisuo (TUT), Teemu Tiainen (TUT), Ilkka Sorsa (Ruukki Construction)

PARTICIPANTS: SSAB Europe Oy, Ruukki Construction, University of Oulu, Tampere University of Technology: Research Centre of Metal Structures, Department of Civil Engineering, Faculty of Business and built Environment, Lapland University of Applied Sciences,

International co-operation was completed with KU Leuven and with Peter the Great St.Petersburg Polytechnic University.

PUBLICATIONS:

J. Siltanen, V. Kesti, R.Ruoppa, "Longitudinal bendability of laser welded special steel in a butt joint configuration", conference paper, ICALEO, San Diego, 2014.

A-M. Arola, V. Kesti, R. Ruoppa, "The Effect of Punch Radius on the Deformation of Ultra-High Strength Steel in Bending", Key Engineering Materials, Vol. 639, pp. 139–146, Mar. 2015.

A-M. Arola, A. Kaijalainen, V. Kesti, "Evaluation of Bendability of Hot-Rolled S960 Grade Steel Using Optical Strain Measurements and FE-Modelling", Key Engineering Materials, Vols. 651–653, pp. 610–616, Jul. 2015.

A-M. Arola, A. Kaijalainen, V. Kesti, "The Effect of Surface Layer Properties on Bendability of Ultra-High Strength Steel", submitted to the ESAFORM2016 conference in Nantes, France, April 27–29, 2016.

Mela K., Heinisuo M., Weight and cost optimization of welded high strength steel beams, Engineering Structures 79, 2014, pp. 354–364 .

Mela K., Resolving issues with member buckling in truss topology optimization using a mixed variable approach, Structural and Multidisciplinary Optimization, 2014.

Tiainen T., Heinisuo M., Tubular Steel Truss Design Using Semi-Rigid Joints, Proc. of Computing in Civil and Building Engineering. Orlando, ASCE 2014.

Tiainen T., Mela K., Jokinen T., Heinisuo M., Optimization of high strength steel tubular trusses, Proc of Eurosteel 2014, September 10–12, 2014, Naples, Italy.

Mela K., Heinisuo M., Economical utilization of high strength steel in welded slim floor box beams, Proc of Eurosteel 2014, September 10–12, 2014, Naples, Italy.

Heinisuo M., Mela K., Tiainen T., Jokinen T., Baczkiewicz J., Rotational stiffness of welded tubular Y-joints, Elsevier, Proceedia Engineering (2015).

Havula J., Myllymäki H., Sorsa I., Haapio J., Heinisuo M., Experimental research of welded tubular HSS T-joints, welding times and moment resistances, IIW International Conference, High-Strength Materials – Challenges and Applications, 2–3 July 2015, Helsinki, Finland, 2015.

Diez Albero, J.A., Tiainen, T., Mela, K., Heinisuo, M. Structural analysis of tubular truss in fire, Tubular Structures – Proceedings of the 15th International Symposium on Tubular Structures, ISTS 2015, pp. 181–187.

Heinisuo M., Haakana Ä., Buckling of members of welded tubular truss, Proceedings of The 13th Nordic Steel Construction Conference (NSCC-2015). Markku Heinisuo & Jari Mäkinen (Eds.), 23–25 September 2015, Tampere, Finland, 2015.

Kukkonen J., Heinisuo M., Comparison of relative volumes of different type of welds, Proceedings of The 13th Nordic Steel Construction Conference (NSCC-2015) Markku Heinisuo & Jari Mäkinen (Eds.), 23–25 September 2015, Tampere, Finland, 2015.

Tiainen T., Heinisuo M., Structural analysis models of steel trusses, Proceedings of The 13th Nordic Steel Construction Conference (NSCC-2015) Markku Heinisuo & Jari Mäkinen (Eds.), 23–25 September 2015, Tampere, Finland, 2015.

Tiainen T., Heinisuo M., Definition of shear force for chord shear resistance check of welded tubular truss K-joint with gap. Proceedings of the XII Finnish Mechanics Days, R. Kouhia, J- Mäkinen, S. Pajunen and T. Saksala (Eds.), Tampere, 2015.

Mela K., Alinikula M., Tiainen T., Heinisuo M., Sorsa I., Suunnittelutyökalu putkiristikoiden mitoitukseen ja optimointiin. Proceedings of the XII Finnish Mechanics Days, R. Kouhia, J- Mäkinen, S. Pajunen and T. Saksala (Eds.), Tampere, 2015. (in Finnish).

Marsel Garifullin, Jolanta Baczkiewicz, Timo Jokinen, Teemu Tiainen, Kristo Mela, Markku Heinisuo. Surrogate model for rotational stiffness of welded tubular Y-joints. The Tenth Annual Scientific Conference and Metnet Seminar Budapest, Hungary, on 13–14 October 2015.

Heinisuo M., Integration of design and manufacturing, presentation in FIMECC MANU Annual Seminar, Oulu, 17.11.2015.

Mela K., Design optimization on steel structures, presentation in FIMECC MANU Annual Seminar, Oulu, 18.11.2015.

Mela K., Korkealujuusteräs putkiristikoissa. Esitelmä: Teräsrakennepäivä 2015. 25.11.2015.

Mela K., Optimization of HSS structures. METNET Workshop 8–9.2.2016. TUT, Tampere.

Tiainen T., MILP in steel frame optimization. METNET Workshop 8–9.2.2016. TUT, Tampere.

Garifullin M., Effect of weld size to the initial rotation stiffness of welded tubular joints. METNET Workshop 8–9.2.2016. TUT, Tampere.

Heinisuo M., Garifullin M., Baczkiewicz J., Jokinen T., Tiainen T., Mela K.. Surrogate models for moment resistance and initial rotational stiffness of welded tubular Y-joints. International Workshop on Connections in Steel Structures 2016,CONNECTIONS VIII, May 24–26, 2016, Hilton Boston Back Bay Hotel, Boston, Massachusetts, USA.

Heinisuo M. Mela K., Tiainen T., Jokinen T., Cost Optimization of High Strength Steel Structures. The 16th International Conference on Computing in Civil and Building Engineering. ICCCBE2016. July 6–8, 2016, Osaka, Japan.

Tiainen T., Mela K., Jokinen T., Heinisuo M., High strength steel in tubular trusses. High Strength Steel Structures Themed Issue in ICE Publishing. ICE Publishing is a division of Thomas Telford Ltd, a wholly-owned subsidiary of the Institution of Civil Engineers. (in progress)

Van Mellaert R., Lombaert G., Schevenels M., Tiainen T., Mela K., Heinisuo M., Global Discrete Size Optimization of Frame Structures. (in progress)

Tiainen T., Mela K., Jokinen T., Heinisuo M., Economical design of high strength steel trusses using multi-criteria topology optimization, IABSE 2016, Stockholm.

Garifullin M., Jokinen T., Tiainen T., Mela K., Heinisuo M., Chord stress function for rotational stiffness of HSS square hollow section welded Y joints. (in progress)

Machine tool energy efficiency and hard machining

CONTACT PERSONS:
Paavo Hopponen (Kesla), Jouko Kiviö (TUT), Sami Niemeläinen (Katsa)

PARTICIPANTS: Kesla, Katsa, TUT

PUBLICATIONS:

K. Ikkala, M. Lanz, J. Kiviö, and E. Coatanéa, "Energy efficiency evaluation method for machine tools," in Flexible Automation and Intelligent Manufacturing, FAIM2015, 2015, pp. 58–65.

K. Ikkala, J. Kiviö, H. Mokhtarian, M. Vainionpää and E. Coatanéa, "Characterization of the cutting parameters in comparison to the machine tool input power", in Flexible Automation and Intelligent Manufacturing, FAIM2016, accepted.

Master's Thesis: Iria Villanueva Lire, Madrid TU, 2014 (in Spanish, extended abstract in English). Manufacturing Process Management with Digital Manufacturing Tools.

Candidate's thesis: Mikko Merikoski, Machining of hardened steels with geometrically defined cutting edge (in Finnish: Karkaistujen terästen työstö terällä lastuavilla menetelmillä), Tampereen teknillinen yliopisto 2014. Published in MANU portal.

PROJECT NAME

PROMAGNET

P3

Jouni Lehtinen/MacGregor Finland Oy
Kimmo Leikko/Metso Minerals Oy
Kari Hentunen/Piikkio Works Oy
Janne Kousa/Raute Oyj
Mika Reinilä/ATR Soft Oy
Leo Torvikoski/Eurostep Oy
Markus Mäkelä/Wapice Oy
Jorma Papinniemi/LUT
Antti Pulkkinen/TUT
Jussi Liikkanen/TUAS
Simo-Pekka Leino/VTT

Persistent Business Transformation with Product Knowledge and Lifecycle Management

Summary of the project's motivation and achievements

Productivity in the value chain depends on the efficiency of operations and the effectivity of the results of the operations as a whole. Not only the efficiency but especially the effectivity of a production network calls for high quality, up-to-date product knowledge, information and data. For example, the effectivity of engineering is affected by the quality of product knowledge, information and data. The availability of up-to-date information on product configuration is a necessity in downstream production activities, such as procurement, part manufacturing, assembly, etc. Finally, the many services across lifecycle processes require correct product data, such as a correct identifier for a spare-part number, and associated information, such as replacement instructions. All the lifecycle processes demand product information and also produce lifecycle data and information that can serve as the basis for lifecycle knowledge for product engineering. The management of this process is called the closed loop PLM (Product Lifecycle Management) [Kiritsis et al. 2011]. In order to better utilize and reuse information for the extended product throughout the lifecycle, well-defined information packages/modules and mechanisms are needed to support product development and to coordinate sales–engineering–manufacturing–delivery processes, as well as for in-use and service processes.

The ProMaGNet project researched and developed common processes and policies for networked product development and manufacturing in the context of operations characterizing the Finnish manufacturing industry. The project created new agile concepts, methods and software for sharing product knowledge between stakeholders within the value chain in an appropriate form. All of these were developed in a network of project partners – the tight collaboration of the parties would not have been possible without ProMaGNet. The characteristics of the

Finnish manufacturing context will be presented later, but the results of ProMaGNet are first highlighted (see Table 1) and the impact of the results reviewed. The remaining sections of the project report describe the means and methods of research and development.

Table 1. **The highlights of ProMaGNet results**

RESULT	IMPACT	REFERENCE CHAPTER
Business oriented PLM implementation models	Enables companies to plan, deploy and benefit from a PLM roadmap for managing a business producing low volume and high variety products more systematically. Business impacts of project decrease lead-time even by 20% for every repeated process is enabled by shared data modules on the repeatability of projects and earlier product-related data.	**Implementing PLM for Low Volume Manufacturing**
Broad re-use of product knowledge and design automation	The systematic means of design automation become a company-wide means of saving thousands of engineering hours over a period of 0–3 years	**Capturing and re-using Knowledge on High Variety Products**
Enhanced Change Management (ECM+) **Change Management as defined in CMII standard with released products** **Proactive change management in product development**	Systematic change processes, review practices and digital product models (ref. 3D+ & IVP) enable substantial savings in time and costs by preventing material shortages and errors (15–25%) from progressing to production and procurement. This will have a radical impact on engineering and production over a period of 1–5 years.	**Updating and maintaining product knowledge throughout product lifecycle**
Expanded 3D (3D+) & Intermediary Virtual Prototyping (IVP)	Enable capturing and transforming product knowledge from all stakeholders, thus design and validation of product's downstream properties and processes already in virtual stage. 3D+ and IVP models structure and conceptualize value creation mechanisms and preconditions for PLM and digitalization of manufacture. Radical impact in engineering and production over a period of 1–5 years.	**Utilizing state-of-the-art digital means for product representation and documentation**
Concept of Location Independent Manufacturing and Supply (LIMS)	LIMS, as a new business model will enable new ways of managing factory plant & technology projects supported by new PLM platform based solutions. Competitive advantage for project and lifecycle business can generate substantial growth and profit in the future, when implemented.	**Sharing and Using product knowledge in manufacturing Networks**
New generation software products for PLM domain published.	Companies can start productive PLM utilization in a shorter time, and can have better user experience with complex PLM information over the end-to-end PLM business process. Collaboration between companies can be enabled in all lifecycle phases of project, product or service. Strengthening the position in domestic and opening doors in international PLM software markets. The PLM market is forecast to grow from US$ 40 billion in 2014 to US$ 75 billion in 2022.	**Capturing and re-using Knowledge on High Variety Products,** **Sharing and Using product knowledge in manufacturing Networks**

The context of the ProMaGNet project

The strategic choices of production approaches are highly determined by the *level of customization in the manufacturing company.* The degree of customer alignment is determined by the customer coupling point and the amount of customer-oriented information (Forza et al., 2007), see Figure 1. The more and the earlier the customer is involved in the business process (design–manufacturing–assembly–distribution), the more customer contact and information is needed. Also, the types and forms of communication on product information is highly affected by these strategic choices.

An important customer-centric strategy in manufacturing is the *Assemble-to-Order (ATO) or Configure-to-Order (CTO)* strategy. In this case, the customer requirements influence the assembly/configure the activities directly, not the design and manufacturing process. Products are made with a set of ready-designed components and modules, but the assembly of this set is customized to satisfy the specific customer needs (Forza et al., 2007). Moreover, communication on product design should be based on standardized processes, documents and identifiers (Pulkkinen et al. 2012).

In the Manufacture-to-Order (MTO) strategy, the customer requirements influence directly the manufacturing activities, not the design process. The company usually offers potential customers a base product that is later modified according to the customer's preferences without modifying the basic design. So, the degrees of flexibility and the modifications that may change the base product are defined in advance and the communication may be partially based on standard design documentation and identifiers.

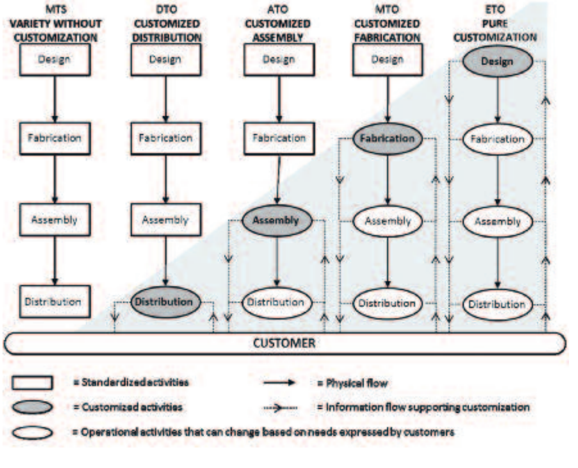


Figure 1. Customization of the product and production strategy (adapted from Forza et al. 2007, p.10)

In pure customization, the most intensive customer orientation is achieved by the Engineer-to-Order (ETO) strategy and products. *ETO or project-based manufacturing* is suitable for unique products that have similar features, and where the production is based on receiving a customer order and developing a technical specification accordingly (Silventoinen et al., 2014).

Project-based manufacturing companies are striving for innovation acceleration, lean supply and product processes throughout the lifecycle. Product requirements and available information are key factors for business success and competitive advantage. However, requirements are always on the move. Customers often change their mind; market drivers change; authorities keep adding new constraints relating to environmental or safety concerns; and sometimes the project encounters difficulties that require a revision of the initial targets. There are several challenges in reusing requirements information, e.g. tracking and tracing of requirements in product-related structures, processes and applications (Papinniemi et al. 2013).

The goal of ProMaGNet

The goal of the project can be summarized as a generic ProMagNet model, which adapts PLM for the typical context of the Finnish Manufacturing Industry. The ProMaGNet model manifested as Product Lifecycle Management (PLM) capabilities that support the transformation of companies. The transformation means the renewal of business operations from the consecutive engineered-to-order (ETO) projects to configure-to-order (CTO) manufacturing approach with a supporting set of well-defined, captured and re-used product knowledge, information and data (Pulkkinen 2007). The case companies were either taking the first steps towards systemic customization or were more advanced companies regarding the matter. The first ones defined and implemented the most essential capabilities and the latter ones enhanced the creation, capturing, management and use of product definition throughout the product lifecycle. The project focused on the capabilities of capturing the product-related knowledge, information and data in a single source, where these assets can be re-used throughout the product lifecycle (see Figure 2).

It can be summarized that previously many companies have been involved with development projects that aim for demonstrations and prototypes of a modular product family definition. However, without strategic investment in the organization capabilities as well as systematic processes and tools, the demonstrations do not ensure the transformation. This was the situation in some of the case companies that rolled out the first PLM system implementations during the project. Also, the breadth of the market offering may be very limited with a demonstration or proof-of-concept project. The ProMaGNet project consisted of industrial cases on PLM implementation, product design systemization, integrating 3D product models into review practices and product configuration, the analysis and capturing of product portfolio as configuration knowledge in sales and engineering configuration systems, etc. The experiences and capabilities developed in joint industrial case-projects and research tasks are collected in the themes of PLM capabilities in later sections.

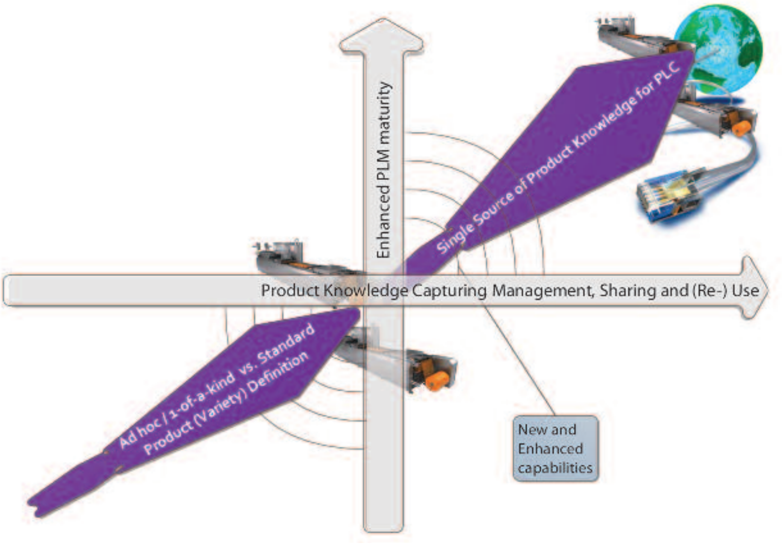


Figure 2. **Developing PLM capabilities for leveraging business needs: the transformation of manufacturing and new businesses**

The participating manufacturing companies were in different phases of the PLM implementation process. Metso Minerals had a sound basis of traditional product data management, and they were expanding the PLM framework towards new processes and tools. MacGregor was boosting their product delivery projects by moving from document-based product data management towards one that was item-based, establishing product platforms and building engineering design automation on many levels. Raute was undergoing a transformation from one-off type projects towards modular product platforms and product lifecycle management, by defining a business oriented PLM model with the intention to support business goals. The company Piikkio Works was building PLM foundations for design automation and increasing integration between ERP-PDM-CAD systems. The software providers and PLM facilitators, Eurostep, ATR Soft and Wapice co-operated with the manufacturing companies and developed new generation solutions for Finnish industry and global markets.

How do processes and organizations enable the achievement of strategic goals besides PLM software and technology?

Business models, value chains and networks contain many processes driven by people who belong to various organizational and networked structures. Making these processes more efficient and effective, for instance by removing waste like unnecessary re-working is one approach to achieving strategic business goals. New business models may even require totally new processes and organizational structures. These transformations can be supported by improved utilization of knowledge in peoples' minds, and the development and implementation of PLM. These kinds of transformations were present in many of the ProMaGNet companies and continued after the project.

Manufacturing and supply of complex and project-specific products is typically conducted within a flexible network of various internal and external stakeholders. These stakeholders need to access, create and interact with up-to-date product knowledge. Concurrent and real-time product knowledge is essential for efficient manufacturing processes. However, the sharing of product knowledge has challenges and also risks. Product knowledge is often available only in one form (e.g. CAD models), which hinders its use among different internal and external functions (manufacture, assembly, logistics, after sales, service). In addition, product knowledge may not be up to date and available as time goes by. On the other hand, sharing of product knowledge carries the risk of core competence leakage to competitors.

In the ProMaGNet project a common objective was to enhance the holistic product-life approach over the traditional functional silos of companies and departments. Besides development of the traditional onwards information flow from engineering design towards production and later lifecycle phases, also the feedback flow backwards to engineering design and product management was a special focus. Companies continue to develop these capabilities beyond the project time limitations.

Implementing PLM for low volume manufacturing

Industrial companies in the ProMaGNet project are sharing the same type of operation strategy, based on customer-orientation with a low-volume & high-variety product base. Companies have set out to improve their competitiveness, each from their own baseline for defining the degree of customization and modularization. In order to describe the relation of volume and variety, the High Mix/Variation, may cover for example hundreds or thousands of active part numbers, a few with active forecasted volume. A Low Volume lot size is dependent on the customer (usually a small order size).

As it is assumed that low-volume & high-variety products are not easy to modularize, this means these kinds of products are seldom or only partly configurable, as they lack modular structures in the sense of Harlou's (2006) standard designs. In project-based manufacturing there is, however, a need to build up the *reusability of product design, components, and modules* utilizing a configure-to-order (CTO) -based modularity (product modularity / platform base).

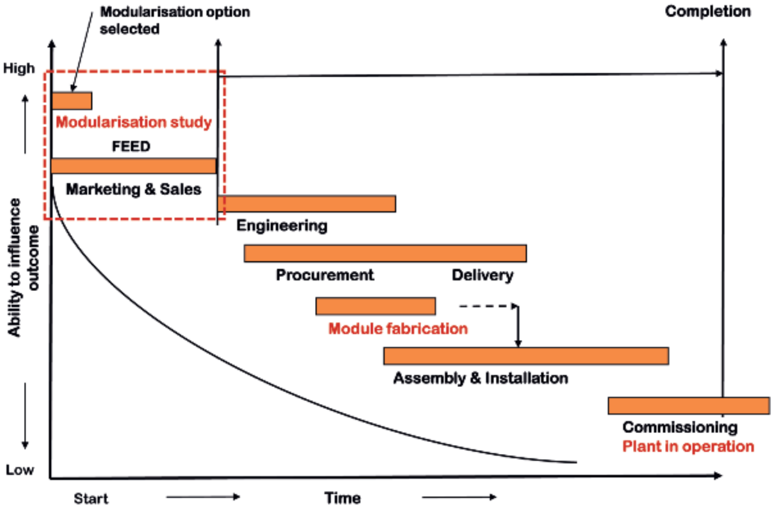


Figure 3. **Modularity at the project level for gaining repeatability**

However, at higher level, supply/delivery projects could be modularized utilizing product platforms and process modularity (Abdelkafi, 2006). The question is: what are the factors differentiating 'project-based products' such that the earlier made designs cannot be reused? A typical answer is that the designs are not standardized modules or they are not easily available. In project-based (ETO) manufacturing *repeatability at project level can be achieved through guidelines for process modularity, workflow commonality and shared data & information objects.*

Repeatability in a company context means reuse of some specific process part of an industrial plant and its machinery.

Project business concepts based on modularity could allow a time decrease of even 20 percent for every repeated process. The modular manufacturing/construction concept could thus bring significant value-added to the normal stick built project concept.

Company impact

> "Piikkio Works has gained results especially in the development of assembly and logistical flow processes. Changes are seen in daily management and measuring targets in different levels of the organization. One big strategic achievement has been the reduction of material and finished product stock. Piikkio Works Oy has also improved design process efficiency and design quality with own CAD environment development as well as by increasing integration between ERP - PDM - CAD systems."
>
> ***Kari Hentunen**, R&D Manager, Piikkio Works Oy*

Deriving the product lifecycle concept and roadmap for PLM

Developing modular product structures, product platforms and configurable product families is not enough for successful product customization. According to Harlou (2006), the definition of standard design includes not only the intention of reuse and the definition of standard design itself, but also the way and the means of documenting the standard designs for re-use. This involves defining configuration processes and setting up support for product configuration. PLM systems and processes are vital in enabling the documentation and the means of reuse. For a company that is taking steps towards systemic customization and CTO, the definition of the PLM strategy, processes and structures are necessities.

Company impact

> "These discoveries we will use to take the next steps and transform our organization toward creating value from product life cycle data, working on topics such as defining tangible and intangible products, applying new PLM functionality and moving gradually from the ETO to CTO business model."
>
> ***Elli Leino**, Engineering Systems Specialist, Raute Oyj*

During the project Raute defined a PLM strategy based on the business-oriented PLM concept for a Finnish project-oriented, low-volume and high variety manufacturing company. The impact of this is a higher awareness of PLM issues. Presumably, the awareness will enhance the transition to systemic customization and implementation of PLM as well as prevent the many errors related to the learning-by-doing approach that may well be the dominant strategy in software implementation. During the project Raute recognized processes and structures in the organization that are not supporting life cycle business optimally, and on the other hand we developed new processes that cannot work without complete and accurate product data. How Raute will succeed in implementing PLM will be a critical strategic factor in sustaining the company's competitive advantage.

Needless to say, PLM is much more than a software issue but also a matter of processes and organizations (Ameri & Dutta 2005). However, the limited time span of the project prevents an objective study on the impact of PLM in the case. Thus, the perception of the company is the validation of the research:

Company impact

"As a result of this project, Raute's Product Lifecycle concept has been re-written to include new approaches for Service offerings, Product lifecycle practices and Digital services. This all will have a major impact on the future development of new products and offering portfolio."

__Janne Kousa,__ Engineering Manager, Raute Oyj

During the ProMaGNet project MacGregor and Piikkio Works also designed for the utilization of PLM systems to achieve improved product data reuse and management. They also studied the relation of PLM at the strategic, organization and process levels, when the purpose of the PLM systems was tightly related to the modularization and parametrization strategies of the companies and also to the enhanced sharing of product information between the engineering, manufacturing, procurement, and logistic organizations.

Capturing and reusing knowledge on high variety products

One theme within the ProMagNet project related to the creation of product data and the capturing of product-related knowledge. The main hypothesis in the theme was that the adoption of the integrated product data model improves the quality of information and enhances the operations of a networked project delivery.

Company impact

> "With the systematic development and implementation of PLM capabilities MacGregor has significantly improved the management of parametric and configurable product architectures. This will improve the efficiency and quality of product development by enabling concurrent engineering practices, change management and knowledge sharing."
>
> ***Jouni Lehtinen**, R&D Director, MacGregor Finland Oy*

MacGregor escalated the use of the engineering configuration concept developed in the previous FIMECC program *Innovations and Networks* (2009–2014). The automatized 3D-model generation was being utilized also for different types of products than in the original case. The use of the parametric CAD model was based on the skeleton model, which was further enriched by configuration software and optimization algorithms. For example, the productivity of the tasks of other stages of engineering, such as manufacturing documentation, were being automatically detailed with the use of computer-aided engineering (CAE) software, such as CUSTOMTOOLS by ATR Soft. For example, the material lists were generated automatically from the 3D model and further used for downstream documentation, which will save tens of engineering hours in each project and elevate the quality of the documentation. The company also invested in others system, such as PDM/PLM and ERP and studied the potential related to the sales configuration as well as to the configuration of operation manuals. Depending on the future strategy of the company, these pieces of software will be implemented after the ProMaGNet project.

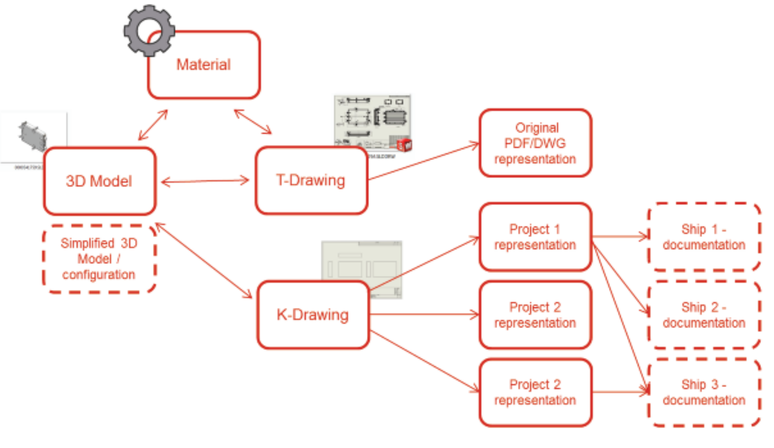


Figure 4. Generation of the K-Drawings (the result of a collaboration between MacGregor and ATR Soft)

Raute defined and classified their product base of hundreds of different project types into three main product-service categories. Also, a comparable set of intangible, but standardized service products were being defined for future implementation. However, the work related to the documentation and utilization of the reusable asset is unfinished, although the concepts are being laid out. The company started to understand PLM as a means of collecting lifecycle knowledge. This may well lead to an enhanced development of lifecycle business offerings, e.g. by utilizing the Internet of Things, Big Data, Simulator Aided Development. Thus, the realization of a closed-loop PLM is potentially beneficial to the business in the near future.

Wapice developed further its Summium configurator and implemented 3D functionality in the sales configurator. It is now possible to integrate the configurator more closely to PLM systems and engineering in general. Also, the 3D constraints and rules can be defined in order to better meet the requirements of the CTO companies.

Company impact

"Wapice has advanced the customer-oriented approach to product configuration by developing 3D-based configuration where 3D-models already existing in PLM systems can be utilized. As a result, the information sharing between non-technical and technical product requirements in customer-sales-production spheres can be significantly streamlined and enhanced."

***Markus Mäkelä**, Business Development Director, Wapice Oy*

In summary, the technology and its novel utilization related to product configuration were being developed in and had begun to deliver during the ProMaGNet project. Furthermore, the singular cases and software systems were being integrated so as to create continued processes and information sharing. Also, the concepts related to lifecycle information practices for installed equipment base management as well as the creating of new (digital) service business were being outlined. The impact related to these is comparable to the utilization. For example, the pay back of an investment in product configuration is achievable in months through larger market potential. However, the strategic investments in PLM as a whole might not have been taken (at least at such a pace) without the ProMaGNet project. These investments have a larger impact as they will integrate product configuration and product knowledge management with PLM.

Updating and maintaining product knowledge throughout product lifecycle

One theme focused on the knowledge engineering methods and product structures, for example, change management and modularity. Engineering Change Management (ECM) may consume 30–50%, and sometimes up to 70% of production capacity. Typically, the complexity of change management is due to the great number of the involved internal/external actors (with their own ambitions), constantly changing requirements, tight schedules, and technically challenging integral solutions. Geographically separated production increases the challenges for the ECM even more, since the location of manufacturing sites, transportation costs, and related services are an essential part and source of engineering knowledge.

The maturity of ECM was characterized as evolving within three dimensions: the content of the ECM process and its implementation; the communication and coordination of changes; and the content of the change, i.e. how changes are "modularized" as change packages. The maturity model was used to characterize the benchmarked companies. The model can support the companies in developing their change management capabilities (Pulkkinen et al. 2015).

The ProMaGNet project produced an Enhanced Change Management (ECM+) approach that includes a set of means and methods for the product development project and a holistic approach to enterprise change management for the changes within production. With its broader stakeholder involvement and processes orientation the method stresses the packaging of changes into releases or updates, as found in other fields (such as in ICT & car manufacturing).

Company impact

"Implementation of the CMII style of change management has enabled a more systematic approach to engineering changes. The change release system makes production planning and purchasing more predictable and therefore more efficient. Benefits can be seen also at vendors because the change packages are easier to handle than a pack of separate changes."

__Kimmo Leikko__, Development Manager, Metso Mining and Construction

A first part of ECM+ is the adoption of ECM as defined in configuration management II (CM II) in low volume manufacturing, which took place in Metso Minerals. This step is remarkable, since CMII can be regarded as a comparable product management method to Lean methodology in production. Configuration management is a standardized methodology for electronic (ANSI/EIA-649) and military (MIL-STD-31000A) industries, but the utilization of CM in the context of project businesses has been a challenge. It has for some time been acknowledged as an important means for improving engineering change management (Inkinen 2008), but the utilization of CM II principles requires not only PLM system capabilities but also trained personnel and an awareness in the organizations. The awareness and training proved to be crucial in the case of Metso Mining and Construction (MAC), when the change management procedures were being implemented. In fact, no essential changes were being made on the PLM system used, but rather in the organization and mindset within engineering. We believe that the new way of managing changes should be disseminated and extended to supply networks, in order to achieve additional impact and productivity leap throughout the suppliers.

Figure 5. The methods for enhancing engineering collaboration and change management in product development

According to our estimations the second part of the ECM+ framework represented in Figure 5 requires an investment in ECM that is comparable to one fifth of the product development project. The part of the approach includes processes, methods and digital tools, indicators and metrics for the execution and management of the product development project. As can be seen from Figure 6, the approach is highly connected to the state of the art digital means and concepts for representing product content (presented in the next section).

We have estimated the significant benefit that can be attained with the first few delivered products, i.e. already within the production of the 0-series. The frontloading of product development is economical when an executed change can be ten times cheaper to procurement before the release than after the release. When the number of these kinds of changes can be counted in hundreds, the savings are substantial. The approach leads to improved engineering quality as well as a time and cost reduction in production ramp-up.

Company impact

"New product development indicators have made it possible to predict the potential of early stage production development benefits. The benefits can be up to 10-times bigger than the invested cost in the first 2 years of a new product life cycle."

Kimmo Leikko, *Development Manager,*
Metso Mining and Construction

In the companies there has been a lot of hidden potential related to engineering and enterprise change management that could be harnessed with the aid of public funding. Without it, the development leap that has been taken would probably have not been taken due to everyday duties and a lack of short-term profit. The enhanced awareness, knowledge and the utilization of state-of-the-art methods requires a strategic investment from the companies' point of view.

Utilizing state-of-the-art digital methods for product representation and documentation

One theme within the ProMagNet project was knowledge intensive processes (such as the sharing, utilization and modification of product knowledge) in global networks with external and internal actors. The main hypothesis of this research theme is the acquisition of substantial direct and indirect savings through the utilization of the integrated processes and the establishment of new value-creating processes within the product life. For instance, the assembly, maintenance service and after-sales are processes that benefit to/from integrated and systemized product knowledge as well as engineering tools and methods that utilize the knowledge.

Boosting new product development projects / Case Metso Mining and Construction

In the case study of Metso Mining and Construction (MAC), virtual prototyping in the integrated product development enabled knowledge sharing and improved utilization of 3D-based visualizations between engineering design and development, as well as with other product stakeholders.

During the ProMaGNet project a comprehensive analysis of current new product development practices was conducted. As a neutral party, researchers interviewed some 20 people from several organizational levels and from nine internal functions (product management, project management, engineering design, product development/productization, procurement, sourcing, production, quality management, and after-market) and representatives of two mechanical supplier companies. The purpose of the analysis was to assess the current strengths and best practices as well as the main development targets and areas where digitalization could create most value within the new product development and the time-to-market and time-to-profit goals. Increased utilization of 3D models and improved product design review procedures were recognized as a potential means for reaching those business targets. These have a positive impact on collaboration, communication, organisational knowledge creation, decision-making and overall management. Increased utilization of digital product models and design reviews enable a frontloading of the NPD process, thus decreasing the need for physical prototypes and costly engineering changes.

Based on the NPD case study of Metso MAC, a 3D+ framework model was created. As part of the 3D+ model, Intermediary Virtual Prototyping (IVP) is a new concept (Leino, 2015) resulting from this research. It underscores the many layers and dimensions involved, from the technical advantages of 3D and virtual environments to the expanded mediating object of a humanistic product development activity system. The 3D+ model includes new generation product processes, organizational design, methods and tools such as virtual prototyping and virtual environments, together with information flow and a richly expanded product data model for the IT system support. The 3D+ model defines how virtual prototyping methods support and benefit various business processes, such as requirements and engineering change management, design for lifecycle, assembly and service support, stakeholder (internal functions and disciplines, and external customers and suppliers) involvement and communication within integrated product development and concurrent engineering.

3D+ contributes to the product lifecycle management (PLM) paradigm by enabling better design and validating the product's downstream properties and processes – such as production and maintenance – already in the virtual product phase, and sometimes already in the product concept phase, before the big decisions have been made. The scientifically proven benefits and impacts (Leino, Koivisto, & Riitahuhta, 2013), (Aromaa, Leino, & Viitaniemi, 2013), (Leino, 2015) of the applications of the 3D+ reference model are related, in addition to the 3D technology, to gaining added value for the product process, people and organization as well in business management and decision-making. From the organizational design and management perspective, IVP is a medium for better context-based communication and collaboration between manufacture, assembly, design and other functions, including the ability to reveal abstract information and tacit knowledge. The improved user interface with the product model enables various stakeholders, from assembly workers to human factors experts, designers, and managers, to understand the model in the same way. All product stakeholders benefit, because designers learn about the required external properties and their relations to design properties. Virtual prototyping and virtual environments were applied mainly in design review meetings where participants from many functions and organization levels were involved. This participatory design approach improved the systematic and holistic view from the perspectives of many stakeholders during a product life-cycle. 3D+ enables the receipt of feedback from production and other product downstream life-cycle stages by the design team already before the physical prototypes are produced. Therefore, it enables the generation of engineering design changes in the early virtual product phase and a decrease in the number of costly changes in the detailed design phase and with physical prototypes and production. Thus, it was concluded that engineering change management (ECM) was one of the main drivers of developing 3D+ in the case company. 3D+ enables catching at least the most critical design flaws before creating the manufacturing documents and physical prototypes. 3D+ also provides for analyzing the engineering change requests, change impacts, and validation of engineering change decisions. 3D+ can be utilized in manufacturer's instructions and manuals, and in the future also in Manufacturing Execution Systems (MES).

Configurable products and variant production require flexibility, which leads to manual, work-intensive assembly tasks and production styles. IVP is particularly beneficial in manual, work-intensive variant production, where human skills and knowledge contribute to the flexibility of the production system. This can be justified by improved communication and understanding between people, and collaboration within organizations, and thus earlier feedback from the downstream life-cycle. 3D+ enables the testing and investigating of several product configurations and variants compared to just one physical prototype. The advantages of 3D+ contribute to the productivity and Lean paradigm of new product development through saved time and resources, through a decreased number of physical prototypes and non-value adding work such as unnecessary re-work and engineering changes. 3D+ enables increased understanding of the product for all stakeholders. It enables getting at the real root problems faster, thus giving earlier and holistic problem solving.

Company impact

"The use of advanced 3D methods has led to better quality in manufacturing/planning and therefore shorter time to profit."

__Lauri Jokinen__, Development Engineer, Metso Mining and Construction

ProMaGNet increased understanding of the intermediary virtual prototyping as a concept, its potential capabilities and benefits, as well as the required pre-conditions for its implementation and utilization.

When the focus of virtual prototyping was expanded from the first technology demonstrations to real, new product development projects, it was understood that it will have a wide impact on processes, organizations, and technology infrastructure, like product data management. Small gains can be achieved locally through incremental steps, but the major benefits can be achieved only when the product life and business is taken as a whole. This can be considered as a systemic and revolutionary paradigm change. Intermediary Virtual prototyping (IVP) and 3D+ must not be considered only as a piece of technology, but as a combination of technology, methodology, processes, and infrastructure in relation to the technology, people and organizations, and management. The value cannot be captured without a holistic view of 3D+. From the PLM perspective the 3D+ model includes three main dimensions (Figure 6): 1) Lifecycles of product definitions and product individuals, 2) information flow and knowledge creation between product stakeholders, 3) product definition maturity, product structures and data management.

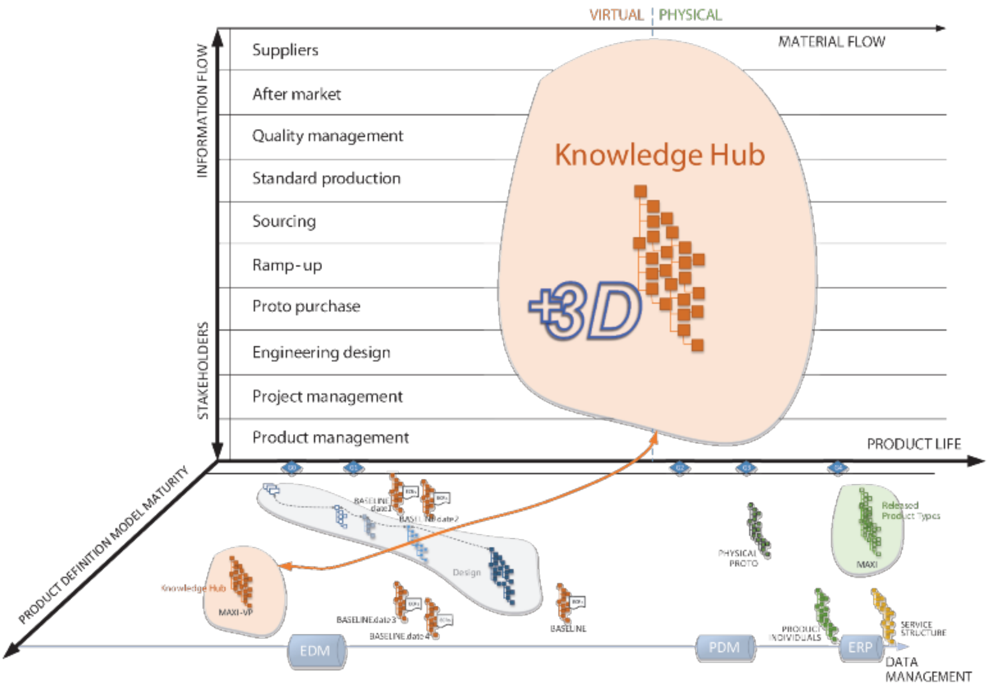


Figure 6. The role of 3D+ in product definition, life and related organizations

These dimensions can be discussed as process, organizational, and technological implications for manufacturing companies:

- **Process implications.** Effective utilization and IVP value capture requires a paradigm change in new product development. Virtual prototyping should be understood as a pivotal process within NPD and PLM. This means that the virtual product process phase should not focus on producing 3D models and manufacturing documents for the physical product process, but it should include the whole product life-cycle. The NPD project and process should be frontloaded so that, for instance, assembly and maintainability analyses and improvements can be done using the virtual prototypes. The frontloading may increase the work and cost at the beginning of the project, but it may also decrease the engineering changes and the cost of physical prototypes in the physical product process phase. The paradigm change also affects how the design model maturity should evolve during the NPD project and process. The way of producing CAD models should better serve IVP.

- **Organizational implications.** It was concluded that one aspect in which IVP creates value is through broad integration and involvement of stakeholders in NPD. Therefore, it is important to recognize and involve the stakeholders at the organizational group level, but also at the individual person level. Hence, it is suggested that NPD with IVP should be organized in dynamic teams, where all the needed stakeholders are involved. On the individual person level, there should be new roles for implementing, developing, and operating virtual prototyping. From the business management viewpoint, it should be understood that IVP does not belong just to a single organizational function, business line, or department, but that it is proposed to be a holistic system and part of product life-cycle management.

- **Technological implications.** The effective utilization of virtual prototyping requires bi-directional data and information flow between virtual environments (VE) and product data management (EDM/PDM) systems. The interface between VE and EDM/PDM also requires a process of data conversion and simplification, which should be at least partly automated to be efficient. However, the product structure (hierarchy), as well as metadata such as item codes and version and revision information, should be transferable bi-directionally.

  In the case study, the possibility to make comments and give feedback directly on the virtual prototype model was one of the most desirable capabilities of IVP. In EDM/PDM, which is the backbone of PLM, the product structure is normally the main framework that constitutes the product information model. Therefore, VP and related data, information, and documents should be referenced with the product model in order to contribute to knowledge management. A virtual prototype as a baseline structure is proposed as the frame for explicit knowledge management, linking the tacit knowledge from stakeholders to PLM. It is proposed to manage the documentation, feedback, requirements, notes, and engineering change requests, for instance, from virtual design review meetings.

Company impact

"The research on parallel structures and factory simulation (Tecnomatix) has given us wider understanding on what implementing fully 3D-based production planning would mean for our company from the perspective of work load, system infrastructure and visual communications."

***Lauri Jokinen**, Development Engineer,*
Metso Mining and Construction

Another aspect of frontloading is the use of multiple product views for different stakeholders. The utilization of multiple views is a concept that was studied in the project by Kariniemi (2014). The concept has had several purposes, such as product variant management, systemization and configuration (Erens & Verhulst 1996, Harlou 2006), but in the project the intention was to study the benefits of utilizing multiple views and parallel structures for integrated product and production engineering. The realization of the concepts was ensured with three case studies with new and operational software. Not only substantial benefits but also the required investment and the capabilities of state of the art software were being recognized.

Sharing and using product knowledge in manufacturing networks

Product-related data is usually created with various design systems and within different stages of product lifecycles, which leads to fragmentation. This has negative effect on the sharing and exploitation of data as well as on efficient change management. Besides data and knowledge of the physical product, all the knowledge about the manufacturing, maintenance, use, services and recycling should be 'modularized', if possible, and linked to the PDM or PLM system. This project produced solutions for the integration of fragmented product and lifecycle data.

Eurostep, Wapice and ATR Soft as PLM facilitators developed new generation solutions for managing effective product data management and sharing in a networked business environment.

Creating capability for Location Independent Manufacturing and Supply (LIMS)

As a part of the ProMaGNet project, Raute has investigated the LIMS concept (Location Independent Manufacturing and Supply). In the future, the traditional ERP-based management system could be a part of the whole business management system. The role of LIMS was considered especially in constantly changing markets and temporary manufacturing sites or geographically separated production. The aim was to significantly reduce the design time and bridge the gap between product development and manufacturing. New knowledge and practices were produced concerning how the possible modularization of a LIMS project relates to the manufacturing and outsourcing strategies and customization possibilities. The ProMaGNet project provides novel insights into the role of 'project modularity' when balancing between customer needs, delivery time and expenses. In practice, this means versatile project variants for customers and better productivity for manufacturing companies simultaneously. These approaches serve for instance the business goals and processes of Mobile Factory (Piikkiö Works) and Location Independent Manufacturing (Raute).

Company impact

"As a part of this project, Raute has investigated the LIMS concept (Location Independent Manufacturing and Supply). In the future, the traditional ERP-based management system is only a part of the whole business management system. When we are working on a global business environment where the focus for executing the projects and services is not based on fixed manufacturing locations, but is based on customer's locations and local infrastructure, we need new know-how and tools (local rules, 4PL logistics, Cloud-ERP, etc.). A concrete base for this is a real time PLM-system as well as progressive usage of related IT-systems. The added-value of what is achievable through this new concept needs to be measured. Part of the project is also to renew KPI-system for business units."

***Antti Aholainen**, Purchase Manager, Raute Oyj*

Creating solutions for the new generation networked PLM platform

Collaboration in manufacturing networks requires new kinds of approaches and solutions. One aspect is the sharing of product knowledge between different manufacturing parties in a global supply chain (e.g. standards, raw materials). Another aspect is the integration and sharing of product knowledge between different engineering disciplines and manufacturing (e.g. feedback).

Company impact

"The ShareAspace Nova platform and InReach is the outcome of an intense development project with reference guidance from some of our key customers. The needs and requirements of Finnish industry are used as valuable input in the development work. The result is a new way for Eurostep and Partners to deliver Secure PLM Collaboration for Joint Ventures, Partner Collaboration and more. To users, InReach means solutions in a shorter time and with increased performance on even larger data volumes. The key is application configuration based on best practice templates."

***Leo Torvikoski,** Managing Director, Eurostep Oy*

Often the integration of different pieces of PLM software has been the strength of consulting companies, which have been able to make integrations and support related migrations with the 1-of-a-kind, project-based approach. Each time, this has involved the time and effort of highly qualified personnel. In ProMaGNet the paradigm was challenged by developing a more industrialized manner for the software integration. This approach may well enable the software companies to expand their market presence to other countries, because the potential for re-use increases.

Company impact

"The ATR Soft strategy is to develop more of our own products and during the DIMECC MANU project we have been able to significantly improve and facilitate this goal. The company has gained a lot of new information about the needs in different sized companies. This information has given many new product or service ideas. The company has been able to conduct numerous studies and demos to verify that its current and planned solutions work correctly and efficiently. This information and knowledge will help ATR Soft to grow not only our product and service portfolio but also the whole company revenue and the number of employees."

***Mika Reinilä**, CEO, ATR Soft Oy*

Utilizing a shared platform and best practice templates aim to boost manufacturing collaboration by consolidating product knowledge from all lifecycle phases (development, design, manufacturing, in-use) providing the manufacturing stakeholders with quality data (i.e. ensuring the data are available, up-to-date, accessible, consistent, correct, etc.), and increasing the reuse of product knowledge between stakeholders and lifecycle phases.

Instead of exchanging information, the focus is on innovative concepts of sharing, both with internal and external stakeholders. The advantage of sharing is to both streamline integration and avoid unnecessary overlapping of work, and therefore to boost the global supply chain.

Further information

CONTACT PERSONS:

Jouni Lehtinen (Jouni.Lehtinen@macgregor.com)
Kimmo Leikko (kimmo.leikko@metso.com)
Kari Hentunen (kari.hentunen@piikkioworks.fi)
Janne Kousa (janne.kousa@raute.com)
Mika Reinilä (mika.reinila@atrsoft.com),
Leo Torvikoski (leo.torvikoski@eurostep.com)
Markus Mäkelä (markus.makela@wapice.com)
Jussi Liikkanen (jussi.liikkanen@turkuamk.fi)
Jorma Papinniemi* (jorma.papinniemi@lut.fi)
Antti Pulkkinen* (antti.pulkkinen@tut.fi)
Simo-Pekka Leino* (simo-pekka.leino@vtt.fi)

*) editors of the final report

PARTICIPANTS:

ATR Soft Oy
Eurostep Oy
Lappeenranta University of Technology
MacGregor Finland Oy
Metso Minerals Oy
Piikkio Works Oy
Raute Oyj
Tampere University of Technology
Turku University of Applied Sciences
VTT Technology Research Centre of Finland
Wapice Oy

REFERENCES:

Kiritsis, D. (2011) Closed-loop PLM for intelligent products in the era of the Internet of things, Computer-Aided Design 43, 479–501.

Forza, C., Salvador, F. (2007) Product Information Management for Mass Customization, Palgrave Macmillan.

Pulkkinen, A., Martikainen, A., & Kuusela, J. (2012). A Framework of design for procurement. In: K. Bernhard, H. Thomas, S. Klaus, & T. Klaus-Dieter (Editors), Proceedings of the 18th International Conference on Engineering, Technology and Innovation 2012, ICE 2012, 18–20 June 2012, Munich, Germany. 307–316.

Silventoinen, A., Denger, A., Lampela, H., Papinniemi, J. (2014) Challenges of information reuse in customer-oriented engineering networks, International Journal of Information Management, 34, 720–732.

Papinniemi, J., Fritz, J., Lipiäinen, N., Denger, A., Hannola, L. (2013) Opportunities of modularity for reuse of requirements information in project based manufacturing, 22nd International Conference on Production Research in Iguassu Falls, Brazil.

Pulkkinen 2007, Product Configuration in Projecting Company: The Meeting of Configurable Product Families and Sales-Delivery Process. Doctoral dissertation. Tampere University of Technology. Publication;712, 183 pp.

PUBLICATIONS:

Huhtala M., 2014. PDM system functions and utilizations analysis to improve the efficiency of sheet metal product design and manufacturing, Dissertation, Lappeenranta University of Technology. 158 p. (http://www.doria.fi/bitstream/handle/10024/97266/Merja%20Huhtala%20dissertation.pdf?sequence=2)

Leino, S-P., 2015. Reframing the value of virtual prototyping: Intermediary virtual prototyping – the evolving approach of virtual environments based virtual prototyping in the context of new product development and low volume production. PhD Dissertation. TUT 2015 (http://dspace.cc.tut.fi/dpub/handle/123456789/22994)

Huhtala M., 2014. PDM system functions and utilizations analysis to improve the efficiency of sheet metal product design and manufacturing, Dissertation, Lappeenranta University of Technology. 158 p.

Huhtala, M., Lohtander, M., Varis, J. 2014. Product Data Management – Defining the Used Terms. In: Fukuda, S. Bernard, A. Gurumoorthy, B. Bouras, A. (editors). 11th International Conference on Product Lifecycle Management – PLM14, held in Yokohama, Japan 7-9.7.2014. P. 387–396.

Huhtala, M., Lohtander, M., Varis, J. 2014. Product Data Management Systems as a Tool in Engineering Change Management. In: Hong, S, H. Seo, J. Moon, K. (editors). Advanced Materials Structures and Mechanical Engineering Conference, held in Je-Ju Island, South-Korea 9–10.8.2014. 396 p.

Laitinen, S., Huhtala, M., Lohtander, M., Kässi, T., Varis, J. 2014. Product Knowledge and Lifecycle Management in Project-Based Manufacturing. In: Song, H, M. Hu, J, W. Son, H, K. (editors). Advanced Materials, Structures and Mechanical Engineering Conference, held in Incheon, South-Korea 3–4.5. 2014. P. 1283–1287.

Leino S-P. Reframing the value of virtual prototyping: Intermediary virtual prototyping – the evolving approach of virtual environments based virtual prototyping in the context of new product development and low volume production. PhD Dissertation. TUT 2015.

Leino, S-P., Jokinen, L., Anttila, J-P., Pulkkinen, A. Case Study on Engineering Change Management and Digital Manufacturing. In: Bouras, Eynard, Foufou, Thoben (eds.) Product Lifecycle Management in the Era of Internet of Things. Springer 2016.

Leino, S-P., Koivisto, T., Riitahuhta, A. Value of Virtual Prototyping – A Strategic Resource Based View. International Conference on Engineering Design, ICED13. 19–22 August 2013, Seoul Korea.

Leino, S-P., Riitahuhta A. Reality – Virtuality Phenomena Model in Virtual Prototyping. Proceedings of TMCE14, May 19–23, 2014, Budapest, Hungary.

Lipiäinen, N. 2013. Improving product information management in global project-based manufacturing. Lappeenranta: 6.7.2013. Master's Thesis. Lappeenranta University of technology, Industrial Engineering and Management. 97 p.

Papinniemi, J., Denger, A., Lipiäinen, N., Fritz, J., Hannola, L. 2013. Opportunities of Modularity for Reuse of Requirements Information in Project Based Manufacturing. In: 22nd International Conference on Production Research (ICPR), held in Iguassu Falls, Brazil 28.7–1.8.2013.

Papinniemi, J., Fritz, J., Hannola, L., Denger, A., Lampela, H. 2014. Lifecycle-based Requirements of Product-Service System in Customer-Centric Manufacturing. In: Fukuda, S. Bernard, A. Gurumoorthy, B. Bouras, A. (editors). 11th International Conference on Product Lifecycle Management, held in Yokohama, Japan 7–9.7.2014. P. 435–444.

Papinniemi, J., Hannola, L. & Maletz, M. 2013. Supporting Product Lifecycle Management with Requirements Information, In: Golinska, P. (Eds) EcoProduction & Logistics – emerging trends and business practices, Springer Verlag, ISBN 978-3-642-23552-8.

Peltokoski, M. 2016. Location Independent Manufacturing – the basic operational needs. 7th Swedish Production Symposium, held in Lund, Sweden 25-27.10.2016.

Peltokoski, M., Eskelinen, H., 2015. Challenges of product manufacturability and cost-effective product data management. International conference on flexible automation and intelligent manufacturing, held in Wolverhampton, United Kingdom 23–26.6.2015. P. 222–229.

Peltokoski, M., Eskelinen, H. 2015. Challenges of product manufacturability and Effective Product Data management. In: Oduoza, C. (editor). 25th International Conference on Flexible Automation and Intelligent Manufacturing, held in Wolverhampton, United Kingdom 23–26.6.2015. 566 p.

Peltokoski, M., Eskelinen, H. 2016. Analysis of feature based modelling in networking environment of sheet metal production. In: 26th International Conference on Flexible Automation and Intelligent Manufacturing, held in Seoul, South-Korea 27-30.6.2016.

Peltokoski, M., Lohtander, M., Varis, J. 2015. Globalization challenges in location independent manufacturing. International conference on flexible automation and intelligent manufacturing, held in Wolverhampton, United Kingdom 23–26.6.2015. P. 530–537.

Peltokoski, M., Volotinen, J., Lohtander, M., 2016. Rationality determination of nautical miles in LIM concept. In: 26th International Conference on Flexible Automation and Intelligent Manufacturing, held in Seoul, South-Korea 27–30.6.2016.

Pulkkinen, A., Huhtala, P., Leino, S-P., Anttila, J-P., Vainio, V.V. Characterising the industrial context of engineering change management. In: Product Lifecycle Management in the Era of Internet of Things: 12th IFIP WG 5.1 International Conference, PLM 2015, Doha, Qatar, October 19-21, 2015. Springer New York LLC. 2016. pp. 618–627. (IFIP Advances in Information and Communication Technology). DOI: 10.1007/978-3-319-33111-9_56.

Pulkkinen, A., Vainio, V.V., Kemppainen, A. A case study on the management of evolving product information content in NPD. In: The Proceedings of 26th

International Conference on Flexible Automation and Intelligent Manufacturing (FAIM 2016). Dong-Won Kim, Bongju Jeong (editors). June 27–30, 2016, KSTC, Seoul, Republic of Korea. 8 pp.

Pulkkinen, A., Vainio, V.V., Rissanen, N. 2013, Case study on the relation of PLM maturity, architecture and business processes. In: A Bernard, L Rivest & D Dutta (eds.), Product Lifecycle Management for Society, Proceedings of 10th IFIP WG 5.1 International conference, PLM 2013, Nantes, France, July 6–10, 2013,. IFIP Advances in Information and Communication Technology, Vol. 409, Spinger, Berlin, Pp. 432–438. DOI: 10.1007/978-3-642-41501-2

Vainio, V.V. & Pulkkinen, A. 2016, A follow-up case study of the relation of PLM Architecture, Maturity and Business processes. In: IFIP Advances in Information and Communication Technology, Vol. 467, Springer New York LLC, Pp. 867-873, INTERNATIONAL CONFERENCE ON PRODUCT LIFECYCLE MANAGEMENT, DOI: 10.1007/978-3-319-33111-9_79

Vainio, V.V., Jokinen, L., Pulkkinen, A. Quality Elements of Engineering Change Requests and Their Effect on Request Processing and Content Comprehension. In: The Proceedings of 26th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM 2016). Dong-Won Kim, Bongju Jeong (editors). June 27–30, 2016, KSTC, Seoul, Republic of Korea. 8 pp.

SOFTWARE, DATABASES, DEMONSTRATORS:

New features and functionalities in Custom Tools
(see: http://customtools.info/)

ShareAspace Nova and InReach
(see: http://www.eurostep.com/2016/03/eurostep-announces-shareaspace-nova-and-inreach-for-rapid-deployment-of-modern-and-scalable-collaboration-solutions/)

3D-features and functionalities in Summium software for configuring, pricing and quoting (CPQ) (see: https://summium.com/)

PROJECT NAME

ACCELERATE

P4

Jaakko Kekkonen/PonssePLC
Petri Huhtala/TUT
Ismo Ruohomäki/VTT

Accelerating Time to Profit

Project's motivation

The starting point for the project was to retain competitive production in Finland. The domestic supply chain has a significant role in the context in which customer-specific products are produced through the efficiency of serial production. This is also a desirable situation in the future, but there are a number of challenges related to this objective. Supplier network management, cost management, and production ramp-up of new products are becoming more challenging because R&D and product design produce new product versions and variants at an increasing pace to fulfill the varying customer requirements.

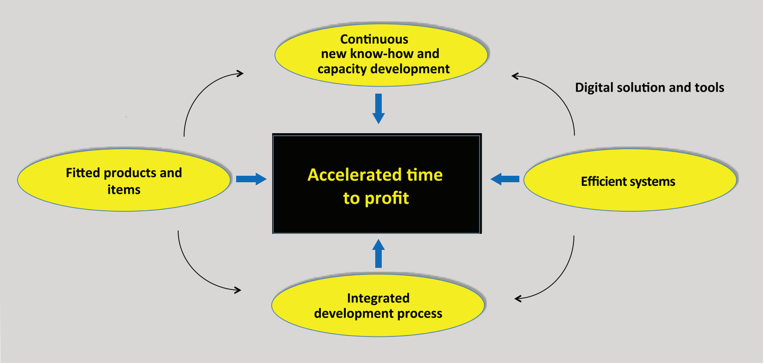


Figure 1. **The main focus areas in the path toward fast profitability**

Maintaining and increasing competiveness requires constant work. This aspect led us to the main goal of the project, which was to create a product development environment that would enable as short a time-to-profit for new products as possible. In other words, there has to be an ability to offer new products to markets in a profitable and fast way. A concept for this integrates fast product development, cost efficiency, and early involvement of the supply network. This concept aims to enable a competitive advantage that is built upon domestic operations and a mainly domestic network. To summarize, this is an environment in which the results of development would flow rapidly from research to serial production, with predictable and manageable costs. This overall objective was approached by four focus areas, which are presented in Figure 1.

Under the focus area of continuous learning and capability development, information is gathered to support the goal-oriented design of products, systems, and processes. This area contributes to creating a real-time snapshot in which the evolution of systems and products is stored. Under the focus area of fitted products and items, and the focus area of efficient systems, products and life-cycle systems are developed so that these fit seamlessly into the development process and boost both the development process and the life-cycle phase. These focus areas promote development that aims for fast profitability individually and collectively. Digital solutions and tools are essential and natural enablers in this context.

Summary of main achievements

In this project, we have piloted digital solutions and tools that:

- Collect, store, and refine data for an organization, to enable learning
- Integrate the product structure from early sketches to after-sales service
- Integrate company functions and other necessary parties to contribute to the development process
- Boost the operation of different systems

A solution that was provided for life-cycle management makes development more manageable already from identifying needs and ideas. Systematic gathering of the needs and requirements from both internal and external customers, and argumentation and documentation of selections and decisions related to products, are the most essential points of the developed solution. Operation is supported by different indicators, which enable, for example, real-time monitoring of sales volumes and the evolution of product-specific demand.

Transferring the focus toward the early phases of the development process is a significant reform. Information and feedback from the life-cycle phases is included in requirement management much more broadly than before. Predefined and documented requirement management controls the deliverables of the product development process. The product process, including design reviews and clear responsibilities, and interfaces between the new product process and customer projects have been defined clearly. This is also important from the supplier viewpoint.

Cost awareness during product development has increased. The ability to estimate costs more precisely increases the organization's confidence in cost information and supports utilization further in operations. Transparency and exactness of the cost information are very important, in order to plan and manage product costs. As a result, the control system produces one cost for each item. It is possible to monitor costs and, if necessary, to make modifications, starting even in the early phases of design. Productivity measurement has been improved, which is important because productivity is a significant indicator in estimating the effects of both product and production development. In addition, pricing of the product options has been developed to be more automatic and transparent, by developing the pricing process.

The modular product structure defined during product development combines design, production, and service documentation viewpoints in a single structure model. These viewpoints were previously considered separately. Continuously updating the digital 3D structure leads to a design environment that is always up-to-date. Later on, a 3D model-based environment can be used in different ways, such as in digitalizing after-sales services.

More accurate review objectives, contents, and schedules will lead to more systematic review operations and collaboration between production and product design. This ensures that critical aspects will be considered during the product development process. Change requests focusing on the production system can be recognized and communicated in time when building production capabilities. In this way, the quality of information can be refined and better decisions can be made. The development of production system capabilities has resulted in a better ability to manufacture and assemble, and further in advanced production ramp-up capability. The work has also generated the fundamentals for the strategic development of the production system.

The development work to streamline the material logistics and supply network has resulted in increased cooperation with suppliers. One sign of this is that the number of companies participating in the annual network day has increased significantly. The development work has resulted in faster execution and shorter response times. Referring to several successful examples, the new operation mode has been implemented for wider use inside the company. In addition, important development needs related to the future have been recognized, and these can be developed systematically. New digital solutions for the supplier interface were developed, to support the increasing and diversifying supplier cooperation. In the development of a supplier extranet, new features were added to cover the collaboration needs, for example, in product development, quality control, spare parts, and services. Communication with the network has become more coherent when all the suppliers in the network have the ability to access the necessary information simultaneously.

Continuous learning and capability development

This area brings together the research related to product life-cycle management, cost accounting management, productivity measurement, and product-specific profitability development.

A solution that is based strongly on serving customer requirements was developed to support product life-cycle management. This solution aims to help in managing needs and ideas, and creating projects for the product portfolio actively, based on the status of the product life-cycle. Product life-cycle management, combined with the efficient processing of product argumentation, aims to serve the customer in the best way possible, and to promote the success of offered products in the market.

The systematic collection of customer requirements is a foundation for starting new product development projects (Figure 2). Each market area will collect, store, and communicate needs to product management. Customer requirements cover both internal and external requirements. Based on the requirements, a systematic product specification can be made. A transparent solution enables the comparison of customer needs between different markets. This will guide product development to focus on satisfying the market need. The product information has to be valid and available continuously. This is supported by a set of metrics that are built into the system. These metrics can illustrate, for example, sales volumes and how profitability develops, for people who are responsible for the product offering.

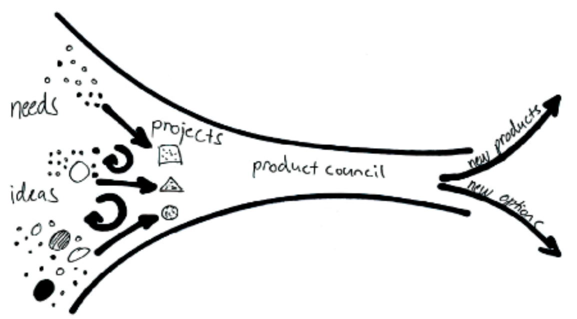


Figure 2. Managing needs and ideas when creating products and options

Collecting product argumentation, meaning the reasoning and documentation behind selections and decisions related to a product, is extremely important during the product life-cycle. It is particularly important that the original need or requirement is followed through the development process. This helps the internal and external argumentation to focus on the customer need. The best results are achieved when the collection of argumentation is immediately started in the early phases of product development, and actively compared to product specifications. For example, solutions developed during design can be immediately documented, and thus this information can be used in making the product argumentation.

Active cost management has an important effect on the profitability of a product range. Influence can be focused on issues that are visible to the end-user (the use phase of the product life-cycle) and on issues that affect internal customers. In practice, the latter means that all the items will fit and be compatible with the different life-cycle phases. In this context, methods or means include process acceleration and item development. The combined effect of these means is to increase the fit between the different systems and the product range.

Targets for development in cost management were recognized and prioritized, based on the current state analysis. Uncertainty of cost information was the main obstacle to increasing cost awareness. Uncertainties existed, for example, due to missing cost information and due to having several different cost values for a single item. The precision of the current item costs was developed by describing the cost accounting process in a way that enabled one cost, regardless of which function used this information. The organization of product design was defined to be responsible for the cost information of new items when they are created. With the PDM system, the transparency of the cost information was increased between different functions. Consequently, the accuracy of calculations has fundamentally improved compared to the starting point.

In the long run, it is the responsibility of a designer to estimate the cost of an item, improve understanding about the cost, and support reaching cost-efficient designs. A working feedback system is required to facilitate learning by doing. This kind of system can help in monitoring the accuracy of cost estimates. More accurate cost information as a basis for cost estimation will also help in making more accurate estimates in the future.

Productivity measurement was also developed and a metric for this purpose was constructed. Productivity is studied from two perspectives: parts manufacture and assembly. The new approach is simple, and it rules out external factors and considers restricted capital. When a company extensively invests in the continuous development of products and production, it is extremely important that the company possesses a reliable indicator for analyzing the effects of changes. A metric for productivity is one of these indicators. The quality of the new metric can be estimated in more depth when more data is captured.

The process of pricing the product options was automated and transformed to be more transparent, based on more accurate cost data. The pricing of product options has a large role in determining the sales price of a product that can be configured in different ways. If the process is complex, it includes the risk of mistakes and will be labor-intensive. Pricing was automated using developed software that replaced the previous Excel applications. At the moment, the pricing of options is considerably faster and fewer mistakes occur. The process is also easier to learn, and this enables different people to do it.

Integrated development process

An integrated development process connects the company functions and suppliers in development at the right time, and establishes solid grounds for product design, procurement, production, and the supplier network. However, no single best-practice process model exists. Dividing the process into phases can act as a backbone for development, but the final success is always dependent on how the process is fitted into and managed in a particular environment. Reasons for dividing the process into phases can be, for example, strategic decision-making, and technological or marketing risk minimization. Figure 3 presents a synthesis of important process characteristics.

- Process must be capable to manage both the development of new products and derivative products
- Strategic decisions relating to products and technology are needed to support the balanced development
- The concept development should be carried out together with right parties before development project start
- Concurrency at the start of development process demands better utilisation of capabilities at the end of development process
- Prototyping, increasingly virtual, is a central part of product development
- The integration depth and timing can vary in supplier integration to product planning and development
- Procurement has an important role in supporting the product development

Figure 3. Important process characteristics

A systematic approach to product definition was developed to support the collection and storage of the information before entering the development phase. Throughout the development process, the main idea is to specify the properties that are wanted from the product. During the design phase, the design is theoretically verified against the requirements, in order to see how well the objective is met. The final validation is made during testing. The pre-defined and pre-documented requirements definition guides the output of the product development process. The life-cycle of the product and the feedback from the product offering are taken into account during the process of requirements definition. A precise requirements definition acts as a communication platform, and possible changes can be shared among the participants. Documenting the results will enable learning. If necessary, the process can be tracked back to check the grounds behind the decision. The approach consists of the following activities:

- Description of the product modularity on an aggregate level
- Conducting the competitor analysis
- Using mind-maps to picture the product properties
- Using Kano analysis to support the discussion and specification (Figure 4)
- Using rating scales to transform customer needs into design criteria
- Establishing the “rules of thumb” for design
- Using cost analysis for target costing
- Determining standard contents for the pre-development phase outcome

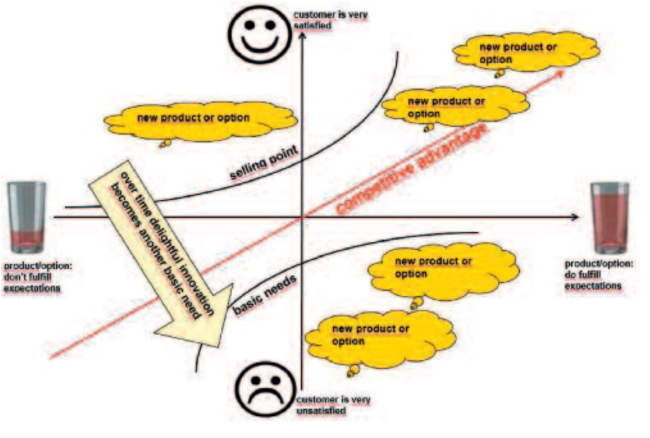


Figure 4. **Kano analysis, positioning of the new products or items from the customer viewpoint**

The integrated process of managing planning and development was based on a literature review and a current state analysis of product development. The process comprises five main phases and predefined sub-tasks in each phase.

The pre-development phase is intended to search, pilot, track, and select promising new ideas. During this phase, the product concept is taken to a level where decisions about development can be made. The product, related life-cycle systems, and development project are planned. In the development phase specifically, the product and also the life-cycle systems are designed. In the testing phase, prototypes are produced for internal and external purposes. The prototypes and life-cycle system properties, performance, and reliability are tested and adapted for the final product and systems. During the production ramp-up phase, production is started and the production network (final assembly, part manufacturing, and suppliers) is adapted to the new product and the related practices, with a gradual volume increase. The mature production phase starts when the goals for efficiency, quality, and time have been reached.

Guiding producibility is a process in which needs and requirements from the production system are communicated to product development. In this process, the production function guides product development from the system and technology viewpoint. The producibility guidance can be seen as an important enabler for building production capabilities, but this also works the other way round. The existing capabilities are like building blocks on which product producibility can be based.

The developed solution model is built on the snapshot gained from the present state of systems and operations. With the help of product and production system modeling, common knowledge about products and sub-systems can be created. Knowledge about strengths, weaknesses, and future developments is gathered into organizational routines. From this information, the input is generated and communicated, starting with the requirements definition. The approach is built on current strengths, such as the current production system and production competence, and it aims to strengthen those further.

A practical example of guidance for producibility is to recognize and communicate which product features to favor, and which to avoid. Integrating the strong production competence and current production system as a part of product development in a timely manner, and above all from an early phase, is a prerequisite for rapid development. The entire production system development will benefit from these kinds of activities.

New procedures for product reviews and co-operation between production and product design were developed and tested. When the focus, the content, and the scheduling of reviews are further defined, this will lead to more systematic work and co-operation between functions. This will ensure that critical issues are dealt with. Production system-related requirements and needs for change will be identified. This promotes the building of production capabilities.

Preparing and updating process and procedure descriptions systematizes the process and ensures that every task produces the expected output. The project manager has better possibilities to monitor and control the product development process and its progress. This policy also sharpens reviews: better quality information is leading to better decisions. Tasks and responsibilities have been clarified, and working groups and follow-up groups have been specified in advance. Special attention has been paid to the early involvement of production and suppliers in development work. The effects can be verified in the long run.

The suppliers involved in the process got a more detailed view of the customer's product development process and its phases. Specifically, the identification of the exact time when the involvement of the supplier brings the greatest value to the customer, was clarified.

The supplier of mechanical components developed a solution in which ongoing "product" projects are monitored by a follow-up board. The solution is used to ensure that the important activities during the production ramp-up phase are committed and that the necessary reviews are held and documented. The document template that was prepared for the production review can be used as a manufacturability report for demanding components. During the production review, the manufacturing and assembly steps are analyzed and potential problems are spotted and solved. Monitoring product projects during development, and holding reviews, has generated a remarkable improvement in the mechanical component supplier's manufacturing quality.

Fitted products and items

Products that are made for purpose should comply with the most important life-cycle systems and should not create unnecessary internal variation in systems despite the external variation. The work done under this theme focused on managing the product structure, starting from the early development phases, design reuse, the development of product cost design, and applying virtual prototyping when developing products.

The modular product structure is an efficient way to create an item structure to vary products based on customer requirements. The guiding principle in the early phase of defining the product structure was the goal to design products using the principles of modularization. The design organization has the leading role in designing products, and therefore it is natural that the product structure that is needed in other functions is created simultaneously. This means that the product/item is the basis for all work, and forms the connection to the life-cycle phases and the back office (for example, the collaboration of network and cost management). Consequently, the design process can also be developed to support products that vary greatly. Modular engineering requires that the properties of the product and the product architecture are defined before starting development. This should be considered in the design of a product program and the management of requirements. A modular product structure combines design, production, and spare-part documentation into one structure model. This concept is presented in Figure 5.

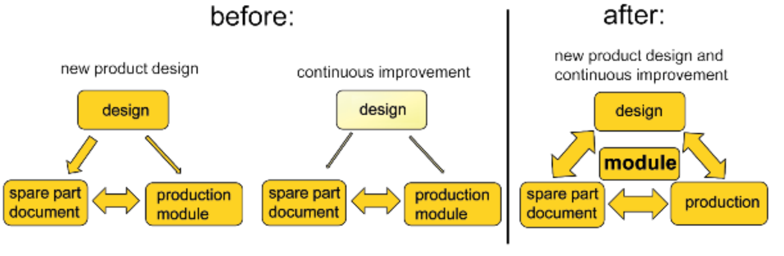


Figure 5. Changes in the way of operating

This solution enables the creation of a design environment in which the product structure integrates concepts of designs, spare-part documents, and production modules into one model (Figure 6). The solution also provides a basis for the integration of similar functions. Because of collaboration and interactions, knowledge about the items is improved in design, and the requirements of life-cycle systems are easier to take into consideration. On the other hand, information also flows easily in the other direction. Continuous improvement can be realized based on the models. In the future, the solution will also enable the modeling of configurations in 3D, digital work instructions, and the definition of spare-part catalogs.

Figure 6. 3D model of a module made using the new modeling practice. The same product structure of the module can be used in design, production, and after-sales

The product structure works as a platform on which various information, such as cost information, can be added. By combining up-to-date cost information with items, more accurate cost estimates can be achieved during the design phase. In the context of designing product costs and estimating calculations, a solution in which procurement cost estimates are made by the designer is used as a basis for calculation, until the realized cost can be implemented in the system. Information systems connect the realized costs back to engineering. This enables monitoring of costs and creates support for decision-making already from the early phases of design. Basic concepts have been built under focus area 1 in the development of cost calculations.

During the research, a new modeling approach, a flow model, was developed. This model can be applied to reuse design information and describe product knowledge explicitly. The flow model is a visual, and company- and product-specific description that aims to capture and visualize the relations of design information, and deduce aspects that need to be considered in design. The flow model includes information and knowledge that 3D models do not include, and vice versa. The purpose of the flow model is not to include all the information that is included in 3D models. This means that making flow models does not remove the need for 3D models, but 3D models are not able to describe the deduction chains that show how a good result can be achieved.

The flow model creates value for managing the big picture, because the model is able to describe requirements from the design and production phases, including experience-based knowledge. Based on theories and industrial applications, capturing engineering knowledge by using flow modeling enables the creation of more complete designs and prototypes, and decreases the number of iterations needed in engineering. A doctoral dissertation is being written on this theme.

The research included studying factors that support design reuse based on a literature review and analysis of real industrial design projects in the manufacturing industry. The fundamental requirement for this is that reusable product solutions exist, and engineers are able to use them. The possibilities for design reuse increase if reusable elements are found easily and if the information about the reusable elements is valid and complete. This creates pressure on IT systems and ways of operating inside companies. Several companies operating in the manufacturing industry, which have successfully designed configurable products based on the principles of modularization, have achieved good results from the design reuse perspective. Focusing on partitioning logic (the reasoning of why the product is or should be partitioned in a certain way), product architecture, sets of modules, interfaces, and configuration knowledge are seen as the most important key engineering concepts in modularization. In successful cases in which design reuse has been increased by applying modularization, the need for delivery-specific engineering has decreased dramatically, and this has enabled cost benefits, for example. Defining the extent of reuse related to the modular product structure before the actual design project makes it easier to estimate the size of the project, and the resource requirements, and enables risk analyses to be made within different organizations.

A virtual prototyping-based collaboration platform was developed for use in product upgrade projects, to support cooperation between design and production departments (Figure 7). The use of virtual prototyping as a communication platform aims to catch possible design errors, and problems regarding assembly properties, earlier during the design process, and to reduce the amount of resources spent on physical prototyping, leading to a faster and leaner ramp-up and a shorter time-to-market in future product upgrade projects. The developed tool concentrates on evaluating assembly properties in collaborative design reviews, which include both design engineers and assembly workers.

Figure 7. **VTT's virtual reality laboratory as used during the case study**

Based on the case study, the company saw potential in virtual prototyping utilizing collaborative design reviews. The benefits of virtual prototyping compared to traditional 3D CAD as a communication platform were recognized. The immersive virtual reality experience enabled better exploration and evaluation of the prototype, especially from the non-CAD users' point of view. Virtual prototyping helped to perceive the upcoming product better. The evaluation of assembly properties was seen as a successful implementation target. The main benefits are incorporated in planning assembly clearances for different items and modules, because of the enhanced 3D visualization and immersive experience. However, it was pointed out that CAD-VR conversion should be eliminated or automated for better acceptance among design engineers. As a result, these collaborative design reviews will be partly applied in future product upgrade projects. The main shortcomings for comprehensive application of virtual prototyping were the need for the optimization of 3D models, and the current status of product data management in the case company, which currently does not support the implementation method as well as it could. The technology will be tested further in the future, to gain more experience about the possible benefits.

Efficient systems

Achieving the fastest time-to-profit goals requires in-depth systematization of all processes, and digitalization where appropriate, doing the right things in each of them and especially in all organizational interfaces. A basic insight in systems development is doing the right things (effectiveness), doing things in the right way (efficiency), and eventually doing the rights things by means of digitalization. These rules were followed carefully in the systematization of processes, when preparing for the production ramp-up phase and further for serial production.

A new purchasing organization structure was arranged, and the key activities were streamlined. A new team was established to take care of ESI R&D activities in the supplier network. This team took over all the supplier network development activities, such as supplier quality, deepening co-operation, and supplier extranet development. New ways of working were based on a process and a collaboration approach, enriched by fruitful scientific and benchmarking-based references.

Punctual supplier communication requires specified contact persons on both sides. There has to be relevant know-how on both sides in order to adapt actions and take care proactively of each other's demands and limitations. This results in smoother transactions, faster response times to inquiries, and prompt quick correction of supply deviations. To put the process in order, a new development team is on the way to implementing a continuous improvement tool based on the Six Sigma philosophy. Quick problem-solving procedures were put into action. Even weekly cross-functional teams (experts, factory-floor workers, and supplier delegates) solve product and process-related problems hands-on. Thanks to the promising effects, this approach will be introduced more widely in the company. The focus of this tool has so far been logistics and assembly feasibility studies, and end-product quality enhancements.

The supplier categorization model was renewed to enhance goal-oriented and versatile supplier network performance development. The new classification model aims to take into account deepening cooperation, significance, and impacts from a supplier life-cycle perspective. The new categorization model divides suppliers into three basic categories, which are:

- strategic suppliers/focal company engineering-based critical components
- strategic suppliers/supplier-based tailored components
- standard suppliers/non-critical components.

In order to achieve a high-performing supplier network, the management of the network must be more goal-oriented, and it should be based on the supplier categorization model giving more precise action plans for development. These action plans are in line with supplier agreements, significance, the scope of the cooperation agenda, and joint development practices. At the same time, supplier assessment methods were also renewed, to be in line with the focal company's own strategy and requirements.

Thanks to these renewals, both sides are constantly aware of their own delivery status, and share real-time delivery information with each other transparently. As a result of the new supplier categorization model, deepening cooperation has expanded to a larger number of suppliers. Remarkably, Supplier Day participation has increased by 20-30%, and the number of signed agreements has increased.

The management of international suppliers compared to domestic ones was not so systematic. International suppliers will be integrated to follow exactly the same procedures – cooperation model, information sharing, co-development – as domestic ones. Naturally, all information-sharing and guidance will be in Finnish and English. Foreign supplier integration will also proceed by widening the scope of Supplier Day.

In order to understand more precisely future purchasing development needs, the so-called supply function's strategic development path and scenario study was arranged. This produced future key development goals, desirable development actions, and finally an alternative supply scenario, which can be proactively implemented when unexpected changes happen. This alternative supply scenario helps in being prepared for sudden changes when the assumed supply function's strategic development does not come true. All in all, supply scenario work strengthens future strategy work.

Both diversified and accelerated supplier cooperation required a comprehensive communication and information-sharing solution. A supplier extranet was the digital solution, serving as a two-way information channel between organizations and covering all aspects of information and co-development needs (Figure 8). The former extranet served mainly the purchasing department in handling information flow in the order-to-delivery-process. The renewal focused on covering new contents, and co-development needs incorporated R&D, supply chain and quality management, manufacturability development, packaging and logistics issues, maintenance, and spare-part management. The supplier extranet was empowered digitally by several new and previously untried functions and processes. The renewal also enabled the introduction of the so-called Supplier Metrics Portal. Through the portal, every single supplier can now follow its own operative status. The supplier extranet boosts willingness to deepen cooperation far beyond order-processing digitalization, although it alone provides remarkable time and resource savings annually.

Through the extranet, all supply network members are simultaneously provided with exactly the same information. Many information gaps and misunderstandings are avoided. Data availability and digital transfer processes promote punctuality, transparency, and reliability. Complementary supplier inquiries are no longer needed.

The extranet is also the home for nonconformity item management: open and handled nonconformities are visible to both stakeholders. Suppliers are also informed about missing items through the extranet, where preventive actions based on root cause analysis also happen.

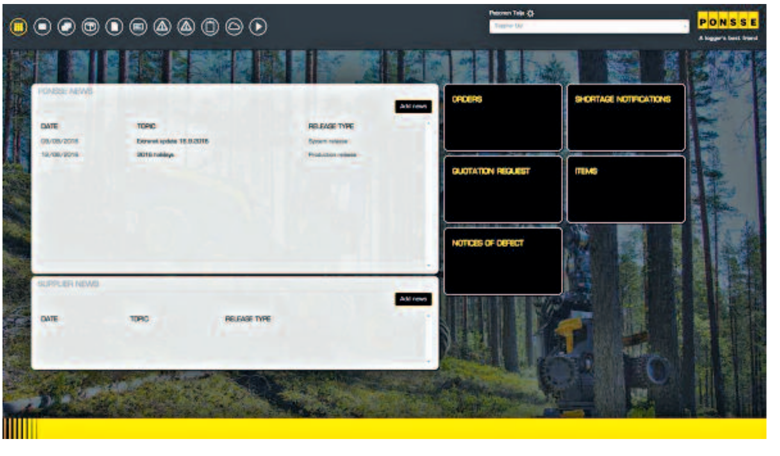


Figure 8. Startup view in the supplier extranet software

Value creation for component suppliers requires diversified participation on focal company processes: besides rapid component deliveries, early participation in the R&D process is needed more and more. The supplier extranet is the primary channel, or digital platform, for handling material logistics, development activities in many forms, performance monitoring, and information sharing. Wide use of the extranet is useful for every single supplier, but for the focal company, those whose capabilities and opportunities enable greater value creation are especially interesting. These are integrated to promote product- and production process-based value creation. As a whole, the supplier extranet boosts not only focal company purchasing operations, but it also systematizes process practices and enhances widely crucial operative processes. Its impacts are related to order, forecast, product, performance, and development benefits. The table below summarizes the benefits of the supplier extranet from the supplier's point of view.

Table 1. Supplier extranet digitalization evolution, and benefits from the supplier's point of view

New digitalized features	Supplier extranet solutions	Effects of solutions
R&D co-development	Engineering and process solution data warehouse, which enables cumulative storage and reuse of solutions and their argumentation	Replaces e-mail-based R&D-related communication. Enables wide reuse of the right engineering solutions. Gives time savings and saves resources.
Extranet introduction	Wide and diversified use of the extranet in materials logistics, supplier network management, and co-development activities	Wide use of extranet supported by clear guidance and ease of use
Order management	Orders and forecasts are transferred digitally to the supplier's production management system. To-do information is also transferred automatically to the supplier's sub-networking partners	Eliminates manual work and activities with no added value, and entire process steps. Speeds up operations and reduces mistakes.
New product/item process method support	Supplier process development and manufacturing-related data are shared in a user-friendly way through the extranet in all relevant data formats	Eliminates data inquiries. Eliminates manual work and tasks with no added value, bringing time savings
Manufacturability reporting and use	Practice of manufacturability reporting and a data warehouse for utilizing manufacturability knowledge	Enhanced usability of manufacturability reports. Better engineering solutions.
Nonconformities, missing deliveries, and corrective actions	Management of nonconformities, missing deliveries, and corrective actions takes place on the extranet	Replaces e-mail-based processes and eliminates personal dependencies. Systematizes and speeds up operations.

An improved way to manage component stock and materials flow was generated by enabling fact-based feedback to suppliers, monitoring the actual effectiveness of the supplier's improvement programs, and following long-term trends for improvements both by suppliers and material management internally. These new metrics and reports support cross-functional improvement work, as well as supplier audits and co-operation with the right areas and material groups. This new reporting system supports material operations by giving up to-date status reports for stock value, cycle time, and material quality on a supplier level, material group level, item level, or by another desired division in the required time period. Eventually, supplier management and development systems will benefit, not only the materials and quality functions. There are more benefits to gain if production, logistics, and design issues are also involved.

Production system design as a part of integrated product development was considered to improve the capabilities and efficiency of early-phase production. The purpose was to increase system readiness to start production by developing system capabilities. The development process can be seen as two interlinked sub-processes from the production point of view. These sub-processes control producibility and build production capabilities. The current strong production competence, and system competence relating to mature products, will form a solid basis on which the new competence is constructed (Figure 9).

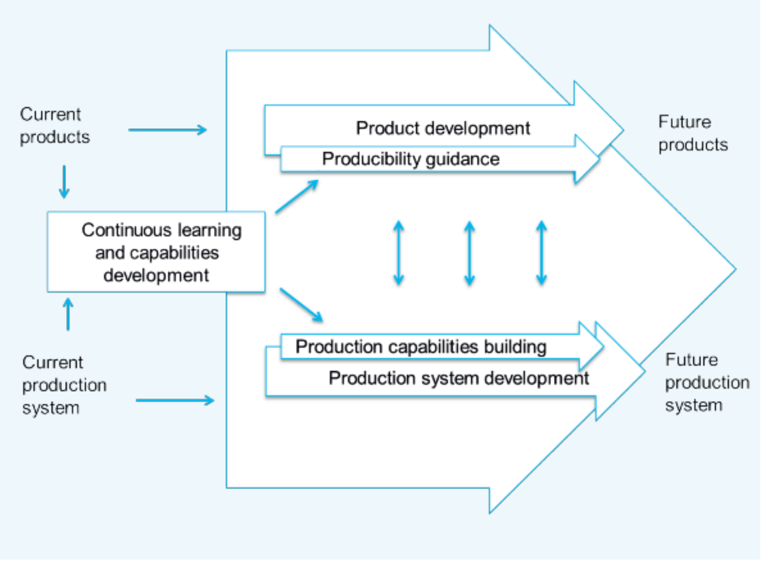


Figure 9. Guiding producibility and building production capabilities, based on the current products and production system

Building production capabilities is a primary task for the production function. The purpose is to make the system ready for the developed product concurrently with the development of the product. The production function can govern this task indirectly by guiding the producibility of the developed product. The guidance of producibility receives inputs from current production capabilities and, on the other hand, produces inputs for further development of production capabilities. This highlights the role of production competence in integrated development. Without understanding the smallest details in production, the development of the most competitive solutions is extremely difficult.

Building production capabilities is anchored in the integrated development process. Needs, requirements, and goals for production are established on the basis of the current status in the production system. The process is planned, and needs and requirements are communicated during the early phase to the integrated development. The production function deals with issues like load and capacity, investment and training needs, preliminary make or buy decisions, and proofs of concept during the pre-project phase. In the preliminary design phase, manufacturing technology and methods are assured. During the detail design phase, the manufacturability details are solved. The use of virtual tools during the design reviews boosts information-sharing between production and R&D. In the course of the testing phase, the production system is partly tested when the first prototype is produced, for evaluation for internal and external customers. The functions and needs relating to production equipment and devices are updated, especially in the area of parts manufacture. The way the work is carried out tries to emulate the final way from the very beginning, even if the working environment and methods may differ, especially in assembly. During the pilot production phase, the production system and the process will be tuned to reach a certain quality level. The method of execution is very close to final. The start of the production ramp-up phase means the start of production. During this phase, the details are fine-tuned while the volume is gradually raised to the target level.

The approach was developed and tested with pilot products during the development process. Practices in design reviews were developed, and the number of reviews was increased. The result is that the production system has better capabilities to handle developed products at the start of production ramp-up. The production function generates knowledge and gains more experience about the developed product. This causes a positive effect on the learning curve and quality level. The research work has created the basis for the strategic development of the production system. The roadmap for the next five years has got a more concrete form. The SWOT analysis for production, together with the related actions, has become sharper.

New digital tools and solutions were also developed. For example, a new audio-visual work guidance system was implemented for digitalizing work instructions. This new video and audio format also helps the working method planner to develop working techniques further without interrupting the work process. The use of this new tool also helps R&D

people to analyze the work process and product assembly. The application of the audio-visual work guidance system has made job initiation easier, enabled self-learning, and helped R&D people to analyze the work process in detail, such as product assembly times.

Collaboration

Key collaborative actions took place within the DIMECC MANU program and among Accelerate project participants. Benchmarking-related thematic workshops among participating companies and research organizations were the most common way to collaborate and exchange ideas. Seminar presentations besides the DIMECC MANU program were arranged in visionary seminars for manufacturing industries. The research and its results were also presented and discussed at international conferences. Collaborative actions between the DIMECC MANU program projects Accelerate and ProMagnet, related to company benchmarking, resulted in a joint publication.

Further information

PARTICIPANTS:
Jukka Teiskonen/HT Laser Oy, Jussi Ohlsson/Stera Technologies Oy, Ari Mäkivirta/Genelec Oy, Juha Karlsson/LeinoCast Ltd.

PUBLICATIONS: Pakkanen J. Brownfield Process: a method for the rationalisation of existing product variety towards a modular product family. Doctoral thesis, Tampere University of Technology, 2015.

Halonen, N., Lehtonen, T., Juuti, T. Impacts of making design decision sequence explicit on NPD project in forest machinery company, NordDesign 2014, August 27 – 29, 2014, Espoo, Finland.

Paranko J., Paranko B., Huhtala P. Productivity measurement at the factory level. Proceedings of Trends in Accounting Research Conference, 7-9 October 2015, Lodz, Poland.

Lehtonen T., Halonen N., Pakkanen J., Juuti T., Huhtala P. Challenges and opportunities in capturing design knowledge. Proceedings of 10th World Congress on Engineering Asset Management – WCEAM 2015, Tampere, Finland.

Pakkanen, J., Huhtala P., Juuti T., Lehtonen T. Achieving benefits with design reuse in manufacturing industry. Proceedings of 26th CIRP Design Conference, June 15-17, 2016, Stockholm, Sweden.

Rytkönen, O. Konfiguroitavan tuoterakenteen muodostamisprosessin kehittäminen, Diplomityö, Oulun yliopisto, Konetekniikan koulutusohjelma, 2015, 92 s. (In Finnish).

Videnoja, J. Implementation of virtual prototyping in the context of product update projects and low volume production, Master's thesis, Tampere University of Technology, Faculty of Engineering Sciences, 2016.

Virta, J., Ruohomäki I: Tulevaisuuden palveluvalimo, VTT, 2015 (In Finnish).

PROJECT NAME

LeanMES

P5

Harri Nieminen/Fastems
Minna Lanz/TUT

Digitalizing of Your Factory Floor

Summary of the project's motivation and achievements

The requirements for production systems are continuously being shifted towards higher flexibility and adaptability. Increasing volatility in global and local economies, shortening innovation and product life-cycles, as well as a tremendously increasing number of variants, call for production facilities that comply with these changing demands. Therefore, tomorrow's production systems must allow quick and cost-efficient set-up once a new product generation enters the production stage. According to Eurostat from 2013, around 10 per cent (2 million) of all the enterprises in the EU-27's non-financial business economy were classified as manufacturing. Manufacturing employed 30 million people, which means that its contribution to employment was 22.6 per cent. The manufacturing sector generated 1,590 B Euros of added value, making the contribution of manufacturing enterprises to added value almost 27 per cent in the EU-27's non-financial business economy (Eurostat, 2013)[1].

These statistics clearly show the importance of manufacturing for Europe. Due to this, there is a great need to actively search for ways to continuously improve competitiveness in order to support the re-shoring of manufacturing activities back to Europe from low-cost Asian countries. EU and international regulations both force and encourage companies to reduce the ecological footprint of their production. At the same time, markets and global competition push companies to produce customized products at low cost on demand, while coping with and also benefitting from fluctuating demand, small batch sizes, global manufacturing, and an ageing workforce (EFFRA, 2012)[2].

[1] Eurostat. Manufacturing statistics – NACE Rev. 2, Key indicators, manufacturing (NACE Section C), EU-27, (sbs_na_ind_r2), (2013)

[2] EFFRA, Factories of the Future Roadmap 2020, Consultation document. Available at: http://www.era.eu/research-a-innovation/ factories-of-the-future-2020.html, (2012)

Today, industry faces challenges originating from fluctuating customer demand, small batch sizes, and long supply chains. The need is to increase productivity and efficiency at all levels, and at the same time the cost generated from non-value-adding processes needs to be lowered. In order to meet the challenges, companies must rapidly adjust production capacity, balance the workforce, and reschedule orders. Responsiveness is fast becoming a new strategic goal for manufacturing enterprises, alongside quality and costs. In short, the dynamic response to emerging events is a key issue in competitiveness in the field of manufacturing. An increase in total efficiency can only be achieved by decreasing the non-value-adding time spent on typing manually, searching for information, rewriting and printing paper work orders, and so on. The digitalization of manufacturing can be seen as one of the key elements in the reduction of non-value-adding time. Operation management systems in traditional industries are based on stand-alone systems that do not communicate within the surrounding environment, which increases the cost of non-value-adding operations and thus slows down the value-adding processes. The LeanMES project strengthens lean thinking at all levels of operation, and thus reduces the time and cost of non-value-adding operations. The LeanMES concept and solution blocks can strengthen the SMEs' daily operations in a highly networked environment by enhancing cross-system observation, planning, and reacting to changes. The current approach aims for a top-down control architecture, where one system rules everything. This is too heavy and expensive for SMEs. LeanMES creates a novel MES concept for networked SMEs that allows them to observe, plan, and react better in a distributed and dynamic production environment. LeanMES supports human operators working in this new and challenging business environment.

The main goal of the LeanMES sub-project was to deliver solutions for real-time digital information flow visibility at all levels, in the factory and in the network. The main aims were to digitalize manufacturing operation management, in order to increase competitiveness, productivity, and agility. The concepts and solutions introduced in this project decrease throughput time, decrease operational costs, allow supply-chain visibility, enhance quality, introduce new products, and modernize manufacturing in general.

Key results and impacts

LeanMES resulted in new product and solution features (with high commercial value potential) for companies. These are the **common LeanMES concept and concrete solution blocks** such as algorithms, dashboards, interaction tests, mobile UIs, intelligent work orders (IWO) and interfaces (Figure 1). The solutions target growth for SMEs, as well as increasing their competitiveness. LeanMES also produced a large number of high-level scientific publications, where the individual solution blocks are described in detail. These can help Finnish industry to gain knowledge about novel ICT solutions and future product candidates.

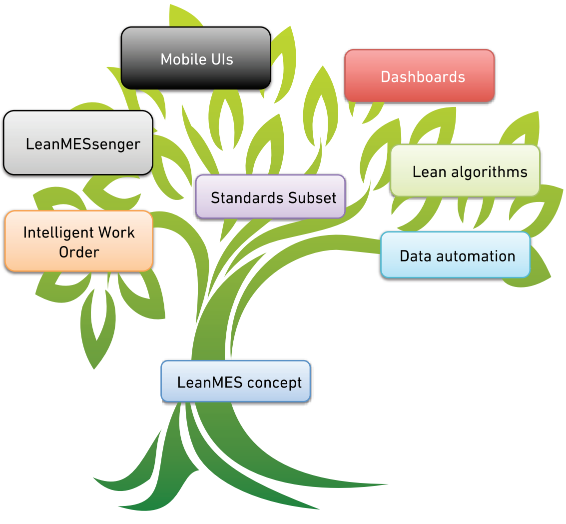


Figure 1. **LeanMES solution blocks**

The output of the LeanMES project delivered a lean, scalable, and extendable concept for a new type of manufacturing operation management (MOM) concept that supports the human operator in a dynamically changing environment. The concept was developed at prototype level, where the verification was done via simulations. The novel LeanMES concept can shortly afterwards be implemented as a commercial tool for SMEs, and in a larger spectrum as human-friendly operation principles in any company. A scientific breakthrough was achieved by providing a LeanMES common concept that is based on open interfaces, standards, and modularity. The LeanMES concept, once implemented as a novel software product, can be utilized in machine, system, and network-level operation management.

At the root: digitalizing manufacturing operation management with the LeanMES concept

In a dynamic operation environment, the manufacturing companies and their networks have to rapidly react to changes and disturbances. In such an environment, efficient information management is crucial. The LeanMES concept aims to provide the right information in the right place, at the right time, and in the right format, and in this way to support production managers, planners, and shop-floor operators in their daily activities. The main elements in the concept are the common language, LeanMES standards subset, and modular LeanMES services located in the LeanMES service layer. The LeanMES concept facilitates both vertical and horizontal integration. Vertical integration refers to interoperability and information-sharing within the organization, between business and manufacturing-level IT systems and machines. Horizontal integration refers to fluent information exchange and visibility in the production network during the order-delivery process.

Figure 2 illustrates the LeanMES concept and associated information flows from the production network viewpoint. For the sake of simplicity, only two companies, Company A and Company B, are included in the figure. However, the figure could be scaled up to include large networks of multiple companies. In the figure, it is assumed that both companies have their own ERP and MES/APS. As illustrated in Figure 2, the LeanMES concept facilitates both vertical and horizontal integration.

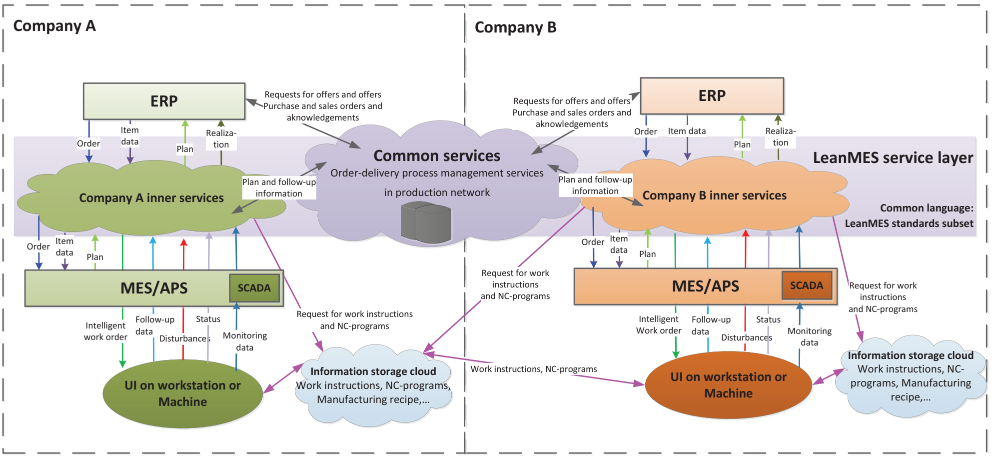


Figure 2. **LeanMES concept and associated information flows**

Strong branches – standardizing the communication interfaces

A small selection of standards relevant to MES were defined as the LeanMES standards subset. The impact of the standards was assessed through design and evaluation of small-scale demonstration systems. Two standards were regarded as particularly important for MES in discrete manufacturing in the future: OPC UA and ISA-95. OPC UA was assessed as quite likely to be one of the essential technologies for data transfer between MES and manufacturing equipment. In turn, the definitions of ISA-95 were considered as relevant and promising for communication between MES and information systems like ERP (see Figure 3).

OPC UA is an IEC standard for communication of industrial data, developed by the OPC Foundation. Typically it is utilized in communication between manufacturing equipment and industrial information systems. In MES, OPC UA can be used for both data transfer between manufacturing equipment and MES, and between MES and other information systems. With OPC UA, it is relatively easy to develop a server that provides a standard-based interface for a combined view of the data about a manufacturing system. A demonstration version of such an aggregating OPC UA server was developed during the project. It is also possible to utilize some other standards in conjunction with OPC UA-based communication, such as PLCopen, MTconnect, and ISA-95. The technology seemed quite ready for practical applications, although its broader adoption is still forthcoming.

ISA-95 is an IEC standard for communication between MES-like systems and other information systems in a manufacturing company, particularly ERP. The definitions of ISA-95 can be utilized in at least two different ways. Firstly, they can be used as an analysis tool for understanding the management of manufacturing operations in companies. Secondly, they can be utilized as part of the software technology for MES. During the project, a demonstration of ISA-95-based communication between MES and ERP was developed. However, the benefit of such ISA-95-based communication can be achieved only if ERP vendors adopt it as well.

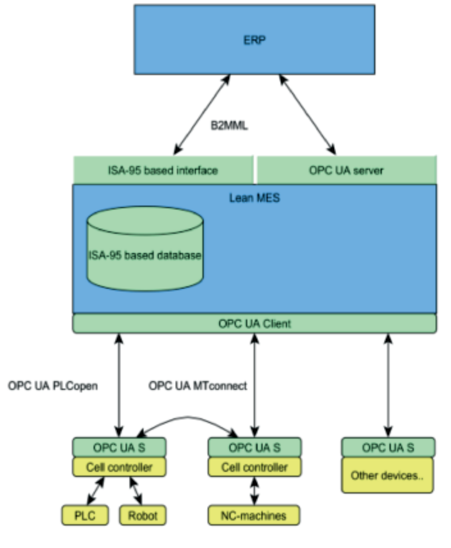


Figure 3. Standards subset – communication links of MES and possible utilization of OPC UA and ISA-95

New leaves – from Excels and post-it notes to fully digitalized manufacturing

1. Intelligent work order

Advancing digitalization of production processes and improving sensor technology are increasing the amount of data that can be utilized to control and improve production systems in various ways. This sets challenges, especially for control systems, because manufacturing system complexities are increasing simultaneously with the need to shorten response times and increase the adaptation capabilities of the system. The typically suggested solution for this is to manage complexity by distributing control to several actors, and to maintain a holistic view in decision-making through sophisticated coordination of activities. The concept of the intelligent work order (IWO) is proposed to assist in this task. It provides a structure that decreases integration complexity, supports de-centralized production control, and improves information visibility at the process level. In order to ease industrial adaptation, IWO is designed to bring fast benefits with only small alterations to companies' existing IT infrastructure.

Traditionally, a work order describes either the process or the end result of the required task. These work orders are commonly delivered to the factory floor in paper format, which means they have limited information content and are difficult to maintain. An intelligent work order is digital and contains up-to-date information on both process (e.g. instructions, NC programs) and output (e.g. specifications, quality control guidance) in a format readable by both machines and humans, as shown in Figure 4 below. IWO is role and context dependent. It can be configured based on the operators' personal characteristics, preferences, and experience. For instance, the method of presenting the work instructions may be modified based on the operator's native language and experience.

An IWO is created only at the time it is needed, after which it calls for the resources required in the process. This approach is intended to ensure that changes made in ISA-95 level 3 and 4 planning systems are automatically considered at the process level. After completion of the task, process data is aggregated to a desired level of detail and stored in the memory of the IWO. Without aggregation, a lot of the data acquired from the process (e.g. signal values) might not be directly very useful to a higher-level planning system. The collected process information can later be viewed from the resource, time, customer, or product point of view. This enables managers to link process information to business processes in a meaningful way.

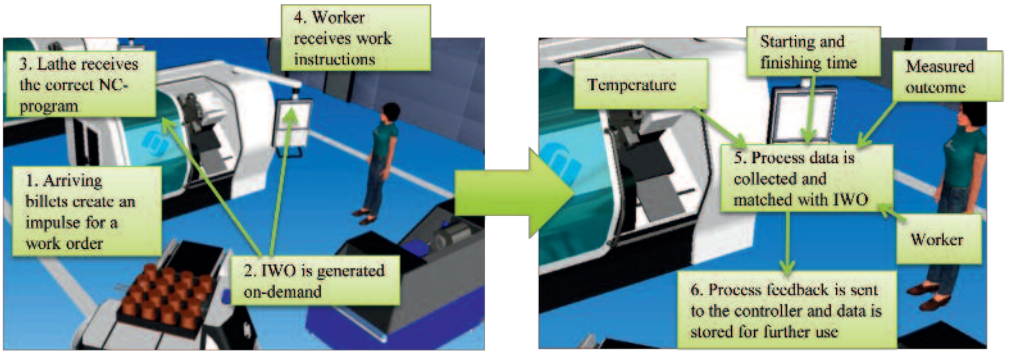


Figure 4. **Intelligent work order principles**

2. LeanMESsenger

One of the LeanMES solution blocks is **LeanMESsenger**, tested with laboratory prototype using industrially relevant data. The **LeanMESsenger** system enables the operators to know in advance what needs to be done next, where, and when. An available and capable operator is guided to the machine or work cell that needs to be operated, just at the right time. The manufacturing task list and its scheduling can be composed from order data in ERP, APS, MES, and FMS systems. Use of structured data from those manufacturing IT systems, such as the use of B2MML format, is possible.

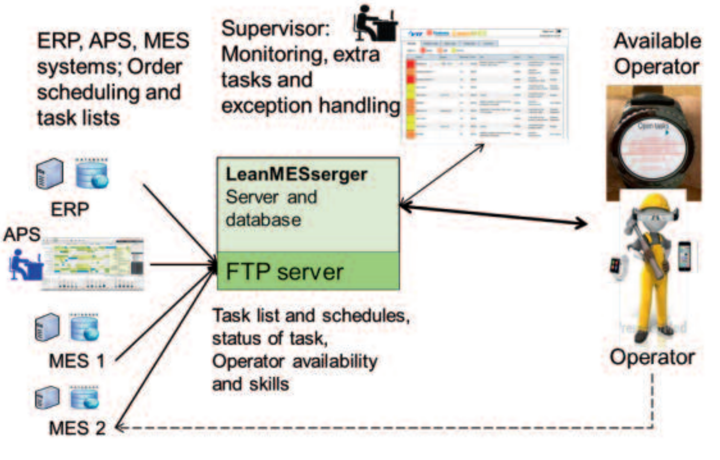


Figure 5. **LeanMESsenger system architecture**

The demo system contains an FTP server, the supervisor's web browser interface, and the operator's smartphone or smart watch interface. The supervisor sees, all the time, the status of the manufacturing process and is able to step in when needed. The supervisor can browse what task each operator is doing currently or in the near future. **LeanMESsenger** shows the scheduled tasks, their order, durations, and the operators planned to do the tasks, as well as tasks that are not accepted. The supervisor can create new tasks, exceptions, and, for example, supporting tasks even for a dedicated operator.

The system knows what the competencies of the operators are, and who is on duty. The operators use wearable user interface devices such as smart watches, as in the demo, or mobile smart phones. The operator can select a suitable task for themselves or reject the task.

Some of the tasks are urgent and they must be done right away. Similarly, some of the lower priority tasks can be postponed or may be suspended (because of a more urgent task) with the minimum disturbance for production. Some operators can have parallel active tasks, and operators who can interrupt their work for a short time without causing any extra waiting time are also considered for availability. As a result, machinery waiting times can be shortened. Management is able to anticipate and eliminate problems based on up-to-date and clear situational awareness. The system also supports communication between operators and management. This context and situational awareness of the operator's task and skills enables the delivery of personalized work instructions when necessary, and helps in data automation, such as the automation of work process data capture from a human operator.

3. Dashboards

Using the results obtained from an industrial survey, three representative manufacturing dashboards have been designed: an operational dashboard for workers, a tactical dashboard for managers, and a strategy dashboard for executives. The dashboards were prototypically implemented using the Dashing framework. Using the Dashing framework, it is easy to construct a dashboard by selecting from the ready-made components or by implementing your own components using technologies such as SCSS, JavaScript, and CoffeeScript. The dashboards were designed in such a way that they can be viewed on mobile devices such as tablets. The actual data for the dashboards is still randomly generated, but in the future, the data should be collected from actual production and machines. The most important KPIs were included in each dashboard, and duplicate information on different dashboards was avoided. The information was added to the dashboard for which it would be the most natural.

Figure 6.
Operational view

Figure 7.
Tactical view

Figure 8.
Strategy dashboard: balanced scoreboard on monthly basis

The first dashboard (Figure 6) is the operational dashboard for workers, which shows the status of the factory floor and job queue. The time period is minutes to an hour. Although the survey showed that all kinds of information are also important in near-real time, the design of the operational dashboard focused on the status of the machines and job queue, as in the survey they were what was most wanted in the case of the minute-hour time-scale. The colors are used to show the status of the machines quickly. Small icons are used to show the status of jobs in the job queue. All this enables the user to quickly see the current efficiency of the shop floor.

The second dashboard is the tactical dashboard for production managers (Figure 7), which shows utilization details, the OEE of the most important machines, the production lead time for jobs, delivery reliability, line efficiency, and reclamations. The time period for the dashboard is a day to a week. The information shown was again selected because it was important for the selected time-frame in the survey. The idea of the dashboard is to contain lots of information, so that the user can also find out the details. Utilization and OEE data are shown in tabular form.

The third dashboard is the strategy dashboard for executives (Figure 8), which shows the forecast for on-time delivery, workers, lead time from an order, total productivity of lines, demand information, manufacturing costs, and inventories. The time period for the dashboard is a month to a year. The dashboard is based on the information that is typically inserted into a balanced scorecard. Again, similarly to the tactical dashboard, the purpose is to have lots of information on a single screen. The difference from the other dashboards is that now there are employee-related KPIs, sales data, costs, and inventory details. Several details are shown in tabular form.

4. Mobile UIs

The term ubiquitous might not be known to everyone. In general, ubiquitous means found everywhere, and when we talk in terms of technology, it means the technology is available everywhere. The technology can be, for example, in the form of tablets, laptops, and mobile phones, which are portable and can be accessed from anywhere. Field engineers or operators working on a factory floor have limited information available to perform a task. Instance information is needed to identify the right equipment needed to diagnose a certain problem. Mobile computing seems to be the best choice to have all the information available to operators, who would be able to work smartly and remotely. LeanMES resulted in prototypes of native and web-based mobile user interfaces (UIs). From the user perspective, mobility enables flexibility in the workflow. In the developed solution, the operator receives orders according to their skill levels and future interests. The operator has the possibility to adjust (within certain limits) the work queue. Information on the queue, batches, storage locations, and other push notifications can be delivered via a mobile app.

Figure 9. **Mobile UIs**

5. Lean algorithms

The lean algorithms work package studied the scheduling of an AS/RS system that has a single one-sided aisle in which two overhead cranes operate. How the two cranes should operate is not a trivial matter, as sometimes it is optimal to fetch packages of cartons in such a way that they avoid each other. The AS/RS has a single input/output location to which the cartons are moved from storage. Figure 10 shows the simulation environment that is used by the authors. The environment was built using 3DCreate software. In the basic delivery of a carton, the operations are the following. First, the empty crane moves over the place where the carton is located. Second, the crane descends to the place where the carton is located. Third, the crane grabs the carton. Fourth, the crane ascends to the top of the shelf. Fifth, the crane moves to above the input/output location. Sixth, the crane descends to the input/output location, and seventh, it releases the carton into the input/output location.

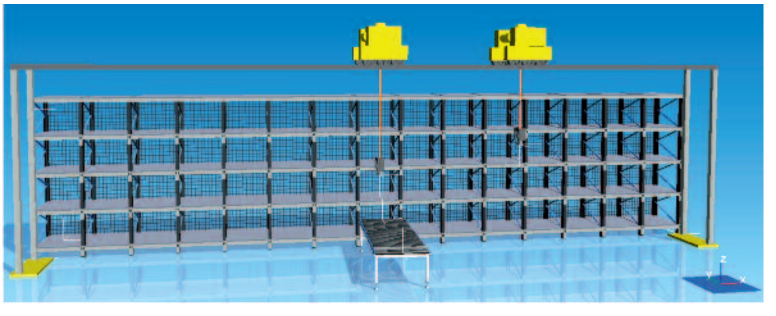


Figure 10. **Scheduling of AR/RS concept**

The lean algorithms research resulted in an agent-based task scheduling system for a job shop using the NetLogo programming language and NetLogo run-time environment. The performance data is used to compare task scheduling methods that include the weighted shortest processing time rule, weighted shortest processing time and idle time allowance rule, and weighted shortest processing time and utilization rule. The prototyped case shows that the use of additional information that is already available and stored in machines or products can help to achieve better results. The communication and negotiation approach between machines and between machines and products proves to be useful and interesting. The results show that when idle times are taken into account, the weighted total flow time reaches its lowest level. If utilization is also considered, the makespan is at its lowest level. The results clearly show that agent-based negotiation rules give better solutions than simple priority rules. However, the rules should be carefully selected, with the objectives of the job shop being taken into account. Future research on hybrid distributed production control could be improved by combining meta-heuristic techniques with simple priority rules in agent-based scheduling of jobs. Second, a shop-floor model could be built that supports flexibility in terms of machines and operation, so that jobs can select an alternative path for their desired operations to be carried out on different machines.

6. Data automation

The identified challenges related to data and information flow on the factory floor are: poor interoperability between proprietary, vendor-specific automation systems, and manual data entry from the factory floor. Manually collected data can be inaccurate and biased, human errors take place, there are delays in entering data, and so on. There is a need to increase the data capture automation level; material and production flow should generate automatically real-time data for better controllability. Today's modern shop floor is a hub of technology, sensors, controls, automated equipment, and humans. If these systems and human workers on the factory floor are interconnected, they can drive efficiency, quality, and flexibility.

In the data automation concept, the goal is to minimize human interaction on reporting of manufacturing process steps, where the human operator is carrying out the task, such as in material handling between automated systems, manual controlled machines, manual welding, assembly, and quality control. The manual process data captured must be connected to other production data stored in various other systems, to get status information that enables visibility and better production control. Inside the factory, production managers can optimize operations and factory scheduling, eliminate unnecessary waiting, and improve workforce deployment. If data is available, selected data can also be shown to the production network, suppliers, and customers.

Technology mapping for potential building blocks of data automation has been carried out: product identification and tracking, parts and operator location, wireless communication methods, wearable and mobile devices, and human system interaction, as well as ongoing research efforts and existing solutions (see Figure 11).

Case studies and technology surveys done in this research project underline that, in today's manufacturing companies, a single solution that fits all end-users is impossible because of the greatly varying manufacturing processes, manufacturing equipment, and IT system landscape. Thus, the solution always needs to be customized to meet individual case-specific requirements. This LeanMES solution block is coupled with LeanMESsenger, mobile UIs, intelligent work orders and the Standards subset.

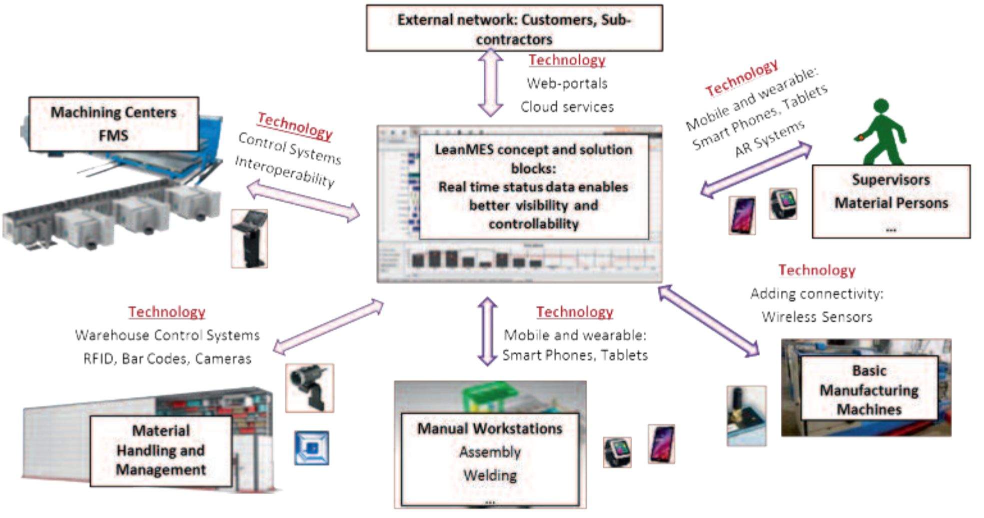


Figure 11. **Data automation – data can be collected from various manufacturing processes**

Fastems' main results

Fastems' main target for the LeanMES project was to enable development in offering elements needed for perfect order fulfilment (the right product, right quality, right place, right time, and right profit margin). With these elements, Fastems can significantly enhance its customers' competitiveness and thus create added value. The work started with MES roadmap creation. The creation process included a profound current state analysis, an ISA-95 compliance study, a positioning study, MES value proposition generation, MES value driver setting, and description generation for the necessary solution blocks. The MES roadmap that was created has had an influence on the company's strategy, and during the LeanMES project, concepts and technologies of solution blocks were also developed.

Data automation: The quality of control information provided by MES is highly dependent on the quality of input data. For this reason, reliable ways of collecting the necessary data from production were studied. During the last period of the project, Fastems will set up an environment for future data automation development purposes. This environment is situated in a living factory, and data from resources is being collected using novel, wireless, easy to set up devices.

Delivery of information: In order to realize perfect order, the capability to deliver the right information, at the right time, to the right actor, in the right format, is needed. In the LeanMES project, Fastems contributed dashboard research, and according to the results, created concepts for configurable dashboards. These dashboards can also be browsed independently of place by using mobile devices. The LeanMESsenger concept was created to deliver task information (list of tasks, schedule, task status) directly to human operators, taking their capability and availability into account. LeanMESsenger is independent of the manufacturing IT system, and different mobile devices, like smart watches, smartphones and/or tablets, can be used as operator interfaces. As a result of the LeanMESsenger research, a demo system was built.

Interfaces: Interface-related research in Fastems' LeanMES project targeted the development of connectivity of solutions delivered by Fastems. Relevant interface standards, as well as applications in device and IT interfaces, were profoundly studied. Based on the studies, solution concepts were created and tested.

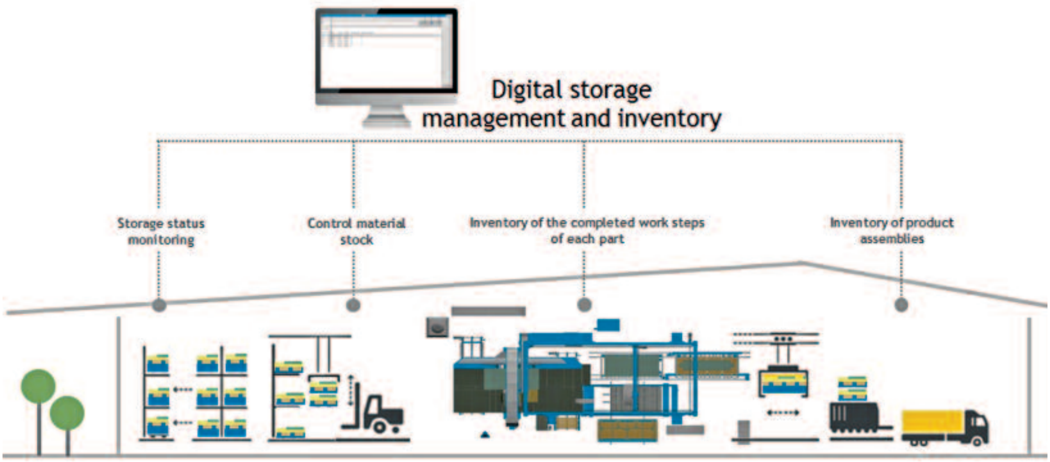
Konecranes Agilon's main results

Konecranes Agilon's main goal was to increase availability, visibility, and utilization of real-time information in the supply chain and supervision of work. The possibility to integrate the customer's ERP system, to be able to boost and streamline supervision of work and monitoring of material flows, was also highlighted.

Automation of supply chain and increase of information visibility: We wanted to automate replenishment order creation and bring more visibility to the order-delivery process with the solution, all the way from the ordering phase to actual delivery. With the implemented solution, material stock balances are monitored against set balance alert limits, and an order is created based on order parameters when the balance goes under the limit. The possibility for real-time monitoring of replenishment needs, created orders, and order reception is also offered to different parties in the supply chain. The achieved solution decreases the work phases in the ordering process and downtime in production due to material shortages, and also increases the transparency of the supply chain to the shop-floor level.

Integration interface as a tool for supervision of work and monitoring of material flows: The first target for the solution was to enable the information flow of incoming work tasks from the ERP system via the integration interface, straight to the work cell where the work task is supposed to be done. The second target was to enable the information flow of actual material consumption back to the ERP system. In the implemented solution, transferred information flows from the ERP system to the work cell are, for example, MBOM (manufacturing bill of materials), added to the used cost centers. The interface also enables the transfer of executed work task and actual material consumption information back to the ERP system, as stated in the target. The solution streamlines the transfer of work tasks from the control system to production, and correspondingly the transfer of executed tasks back from production to the control system.

Finn-Power's main results



The main goals of Finn-Power were to develop new models and technologies to realize actual cost and time accounting (e.g. material and time consumption per part), storage management optimization, and a feedback loop to ERP systems. The development plans included better material reservation, traceability, and quality backtracking technologies. Generally, the support for just-in-time manufacturing in a very dynamic production environment was considered to be a highly desirable goal for Finn-Power.

During the LeanMES project, several new technologies and methods were developed. Concrete solutions were a pilot case for an electronic Kanban system, which was developed and piloted in the customer case. The second solution was the advancement of Finn-Power's more digital and intelligent work order concept. During this pilot, different mobile user interfaces were generated and tested to find the optimal technology combination with respect to usability, technical maturity, and maintenance. The test and analysis results will be explored in the future, when considering new extensions to the Tulus toolset. The company's internal strategy is to move to digital and later on intelligent work orders (possibility to abandon paper-based work orders), and therefore LeanMES has contributed valuable analysis, testing, and partial results for this.

Delfoi's main results

Delfoi develops, markets, and sells web-based Delfoi Planner software, which is a solution for the production planning, scheduling, and control fields. The LeanMES project has been a very important framework for Delfoi's research and development process for developing the next-generation product platform.

In the LeanMES project, Delfoi has done pilot projects, co-development, and solution co-marketing with consortium members within the APS/MES domain. Several integration standards have been studied and some prototypes, such as the B2MML interface, have been tested. This will be further developed as a part of the new interface capabilities. Delfoi has examined cloud-based capabilities and requirements, which was also partially piloted in cloud-based training for operation management training at TUT. Delfoi has also researched multi-site and supplier visibility together with the research partners. A SOP optimization study was done, together with Aalto University, to develop a new SOP module for the Delfoi Planner solution during the next few years.

In the Lean MES project, Delfoi has studied and designed a new graphical user interface (GUI) for cloud-based service models. A new mobile GUI prototype for MES has been developed. A KPI and dashboard reporting prototype was developed. Delfoi will further develop and implement the results for the upcoming new platform for Delfoi Planner.

The LeanMES project has helped Delfoi to share ideas, research, and innovations with consortium members. As a result, a new next-generation platform for Delfoi Planner is under development. This will enable Delfoi to meet the future needs of cloud-based planning and control for the industrial Internet domain.

Delfoi plans to continue to develop proof-of-concept solutions in three new business areas. First, integration details between different production IT systems are explored. Second, such data-automation solutions are studied that will help in simplifying or removing manual work from the shop floor. Third, intelligent solutions, such as scenario-based planning and optimization, are studied to improve the current sales-and-operations (SOP) planning module. In addition, cloud-based capabilities are further exploited and developed during the project.

Logistic's main results

The goal of Logistic in this project was to create a digital revolution in a Finnish machine shop, especially in the field of information sharing. In a supply chain, the information flow usually goes from the end consumer to upstream manufacturers and to material vendors. This information might even be outdated when it reaches the material vendor, which causes a bullwhip effect. By increasing the information sharing in a supply chain, both downstream and upstream, the supply chain becomes more effective against other supply chains. This goal can be simplified into one sentence: the right information, in the right place, at the right time, and in the right format.

In order to achieve this goal, Logistic needed to reach these milestones:

1. **Current state and future state analysis:** First, we needed to model the processes and information flows in our supply chain. In a future state analysis, it was evident that in order to improve information flow, the number of different programs and databases needed to be reduced. It was also clear that if one goal was to increase the amount of data in the system, the other goal must be to show only the necessary information to the right person at the right time. Therefore, different user roles and their KPIs needed to be configured. At the end of this stage, Logistic invested in a system that enabled all this to happen. The investment reduced the number of different databases by more than 50 per cent.
2. **Role-based user interfaces and dashboards:** We divided our user views into strategic, tactical, and operational interfaces. The strategic interface is the most visual interface, and it is used by the CEO, for example. The CEO needs to analyze lots of different graphs in decision-making, and usually less data filling is required. The CEO is mostly on the move, so this user interface is also available on a mobile phone. Now our CEO can access real-time cash-flow information wherever he is. Operational interfaces are used by employees on the shop floor, so the main focus was to create an easy-to-use system where filling the information is simple and there are as few clicks needed as possible. Between the operational and strategic dashboards, there are tactical dashboards used by managers.
3. **Automated reports and data automation:** In this part, we tested different reports in our supply chain. First, test models were created manually so that we could see what kind of information would be useful. After that, the reports were automated so that our customers would receive their daily or weekly information via email. There is still a lot to be done in this area.

Ponsse's main results

Ponsse's key activities during the project focused on collecting data from and measuring and reporting the performance of the factory, as well as on developing the current and planning the future MES system for the company. Data collection has been improved and automated, both in part manufacturing and assembly. Increasing the amount and improving the accuracy of data collected from production, supports and improves production planning and control.

Performance measurement and reporting, which are also linked to the dashboards studied in the LeanMES project, aim to improve situational and status awareness within the company. Performance measurement and reporting enable monitoring of the status of production, as well as identifying deviations from the plan and reacting to such situations.

With regard to MES systems, commercially available MES and WMS systems have been evaluated and piloted during the project. The usability and UI of Ponsse's MES system has also been evaluated and improved, in order to simplify the use of the system. These activities also contribute to clarifying the vision of the future MES at Ponsse.

HT-Laser's main results

For HT-Laser, the main goal of the project has been to implement the lean philosophy and practices in different units (in Keuruu, Haapamäki, Kaarina, Härmä, and Vieremä). Varissaari (Keuruu) was chosen to serve as the pilot location. The discovered working methods, theoretical background, and concepts of the Varissaari pilot have also been replicated in other HT-Laser units. Broad-scale lean thinking has helped in reducing waste throughout the organization, and has brought economic benefits.

Varissaari pilot: Implementation of a new production line: During the project, HT-Laser built a new production line in the Varissaari unit. The line has been implemented following the principles of lean process management. Value stream mapping (VSM) and data analysis were used in developing a new process model for highly variable production. Line balancing and focus on production flow have led to good results, reducing throughput time and variation in production. The SMED method has also been used to reduce set-up times and working methods in the organization.

Improved flow of information: The other major focus of HT-Laser has been improving the information flow within the company and with customers and suppliers. Many development practices have been implemented concerning the information flow. Work instructions have been standardized and the documentation has been improved with video recordings. This has also helped in sharing tacit knowledge throughout the organization. Workers can now report defects to a cloud service using smart phones. The service (called "Hoksu") is provided by PalveluPisara and can easily be configured to serve the needs of different HT-Laser units. HT-Laser has defined several requirements for internal information systems, such as the parallel use of documents. The need for an extranet was also apparent. Several IT systems have been extensively compared in different units (e.g. IntoSome, Yammer, Sharepoint, Google Apps).

Further information

CONTACT PERSON(S):

Harri Nieminen (Fastems)
Prof. Minna Lanz (Tampere University of Technology)

PARTICIPANTS:

Fastems
Finn-Power
Delfoi
HT-Laser
Konecranes
Logistics
Ponsse
Aalto
TUT
VTT

AALTO UNIVERSITY: KEY PUBLICATIONS

Tokola, H., Järvenpää, E., Salonen, T., Lanz, M., Koho, M., Niemi, E., 2015, Shop Floor-Level Control of Manufacturing Companies: An Interview Study in Finland. Management and Production Engineering Review. Vol. 6 (1), pp. 51–58.

Tokola, H., Niemi, E., Kyrenius, P., 2015, How Lean transformation affects scheduling, Robotics and Computer-Integrated Manufacturing., DOI:10.1016/j.rcim.2015.09.012.

Tokola, H., Niemi, E., Avoiding Fragmentation in Miniload Automated Storage and Retrieval Systems. 2015 IFAC Symposium on Information Control in Manufacturing (INCOM 2015), Ottawa, Canada, May 11–13, 2015.

Tokola, H., Gröger, C., Järvenpää, E., Niemi, E., Designing manufacturing dashboards on the basis of a Key Performance Indicator survey, 49th CIRP Conference on Manufacturing Systems (CIRP-CMS 2016), Stuttgart, Germany, May 25 to 27, 2016.

Seilonen, I., Tuovinen, T., Elovaara, J., Tuomi, I., Oksanen, T., Aggregating OPC UA Servers for Monitoring Manufacturing Systems and Mobile Work Machines, 21th International Conference on Emerging Technologies and Factory Automation (ETFA 2016), Berlin, Germany, September 6–9, 2016.

2 journal articles, 9 conference publications, 4 MSc theses, 1 DSc thesis (partly funded by LeanMES)

TUT: 3–5 KEY PUBLICATIONS (+ total number of publications)

Järvenpää, E., Lanz, M., Nieminen, H., LeanMES concept – An approach to manage order-delivery information in a production network, Proceedings of 26th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM 2016), 2016.

Toivonen, V., Järvenpää, E., Lanz, M., Closing the Gap – Improving Production Control with a New Layer of Decision Making, Proceedings of 26th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM 2016), 2016.

Järvenpää, E., Lanz, M., Lammervo, E., Agility Challenges in Finnish Manufacturing Companies – Manufacturing Operations Management Viewpoint, Proceedings of International Conference Advances in Production Management Systems (APMS 2016).

Järvenpää E., Lanz, M., Tokola, H., Salonen, T., Koho, M. (2014). Production planning and control in Finnish manufacturing companies – Current state and challenges. Proceedings of 24th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM 2014), June 2014.

2 journal articles, 8 conference publications, 3 MSc theses, 1 magazine article, 13 LeanMES presentations nationally and internationally,

VTT: 3-5 KEY PUBLICATIONS (+ total number of publications)

Koho M., Tapaninaho M., Järvenpää E., Heilala J., Lanz M. (2015). Sustainability Performance Measurement and Management Model. Proceedings of 25th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM2015), June 2015.

Tokola H., Järvenpää E., Salonen T., Lanz M., Koho M., Niemi E. (2015). Shop Floor-Level Control Of Manufacturing Companies: An Interview Study In Finland. Management and Production Engineering Review. Volume 6, Number 1 . March 2015, pp. 51–58. DOI: 10.1515/mper-2015-0007.

1 journal article, 2 conference publications, 2 national magazine articles, 3 DIMECC MANU reports, 1 public demo at Manufacturing Performance Days 2015, several LeanMES presentations

PROJECT NAME

Emerging Technologies towards Additive Manufacturing, Sustainability and Smart Factory

P6

Jouni Partanen/Aalto University
Kai Syrjälä/Kaidoc Oy
Antti Salminen/LUT
Eric Coatanea, Eeva Järvenpää, Minna Lanz/TUT
Juhani Heilala, Veli Kujanpää, Saija Vatanen/VTT

TASK 1 Additive Manufacturing

Summary of the project's motivation and achievements

The project aimed to increase the future competitiveness of DIMECC MANU companies by increasing their understanding in additive manufacturing (AM) technology. Additive manufacturing, also known as 3D printing, was recently described as "the manufacturing technology that will change the world". AM technologies are fundamentally different from conventional manufacturing processes in terms of cost, lot size, and geometric product complexity. The potential of AM technology is not used nor even understood properly, because it is relatively new and designers have not been able to implement it or simply do not know all its possibilities.

The project started by monitoring the possibilities of the available AM technologies from the DIMECC MANU companies' point of view. Companies were interviewed, and the possibilities of the AM technologies were introduced to them. During the interviews, practical cases of companies were found. Studying AM manufacturing in those cases was done in the next phase of the project. In a literature review, three road-maps were selected to show the current status of additive manufacturing technology. These were uploaded onto the DIMECC MANU web pages. In addition, a one-day seminar was arranged with DIMECC MANU companies, where the needs and possibilities of AM were thoroughly brainstormed. Some topics pointed out previously were highlighted more deeply by detailed analysis and research, and also realized by suitable cases selected in earlier interviews. One of these issues was a closer examination and determination of process limits, to be able to increase process efficiency in AM.

The final achievements of the project were as follows:

Achievement 1. Eleven cases of additive manufacturing technologies for DIMECC MANU companies were realized during the project. The cases represent different types of manufacturing, materials, and design. These cases have increased the awareness of possibilities of AM technologies, and encouraged the DIMECC MANU companies to use them. Additionally, companies have learned where AM technology could be the best choice.

Achievement 2. A practical guidebook for industrial use was written. It is based on the earlier information gathered from international roadmaps and publications, national information on lectures, and publications. It also includes several major case studies executed in the project. The guidebook is supposed to be an aid for industry engineers who design AM products or plan AM production.

Achievement 3. The studies carried out showed that it is possible to produce large products by welding AM components either to each other or to conventionally manufactured components.

Key results and impacts

The key results, namely the industrial cases, the practical guidebook, and the studies on large components made by additive manufacturing, are discussed as follows.

1. Industrial Cases

The cases studied were selected based on the interest of the DIMECC MANU companies and the general importance of the cases. The cases were in different materials: tool and stainless steel, aluminum, copper, Inconel, plastics, and alumina. Many of the printed cases were studied in their practical use, to test the performance and competitiveness against conventional technology. The cases were:

- Steel core for an injection molding tool
- Robot gripper with inserts, turbine blade, and a stand for the blade
- Plastic support for an automatic store
- Adhesive nozzle for a glue applicator uni
- Chuck for a plywood machine
- Support plate for a composing system
- Sand-casting mold and core for a hydraulic block
- Hydraulic block made with sheet lamination
- Hydraulic block with optimized channels
- Copper inductor for a gear-hardening machine
- Several alumina components

As an example, the steel core for injection molding tool, made for ABB, is described in more detail as follows:

The cooling properties are of major importance in injection molding, because they essentially affect production efficiency. Steel cores with several types of cooling channels were 3D printed using a powder-bed fusion method at VTT. Figure 1 shows the cone-shaped elastomer sealing chosen as the case product.

Figure 1. **Elastomer seal manufactured by a 3D printed core**

Different choices for cooling channels are shown in Figure 2. The one on the right shows the conventional design, which was also 3D printed for comparison.

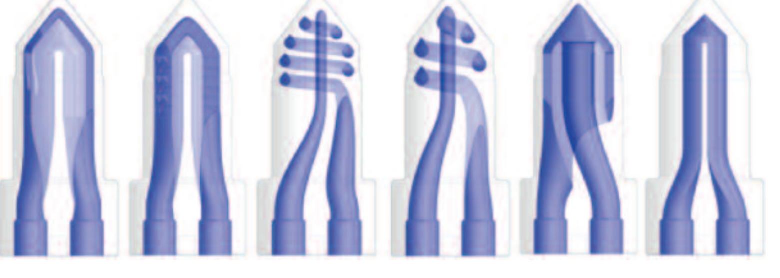


Figure 2. **3D-printed core types, the one on the right is the conventional one**

After 3D printing, the necessary heat treatments (stress relieving, hardening, and tempering) and final machining were done. In Figure 3 (a) and (b), the core is shown before and after machining.

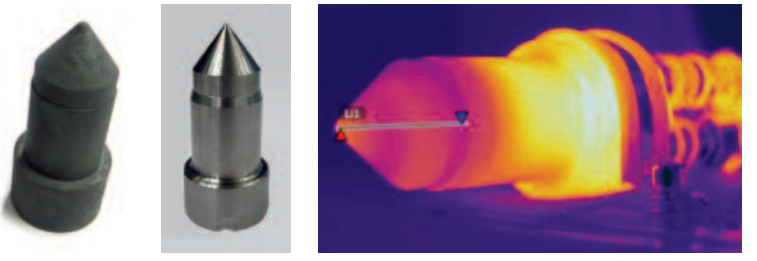


Figure 3. **The core before and after machining. Infrared image during injection molding**

The process temperature of the core was tested by infrared imaging during the test process in ABB, as shown in Figure 3(c). The tip of the core cools very efficiently during the process because of the optimized internal channels. Due to the more rapid cooling, the process can be adjusted more accurately, and the cycle time is cut by more than 75%.

The ABB case is a good example of how 3D printing has major potential in the tooling industry. In mass production, it can bring remarkable cost savings.

2. Practical guidebook

A practical guidebook was written to show the status of additive manufacturing, and to help industrial engineers in selecting the technologies for practical manufacturing and design, and to make the right decisions when choosing the systems for 3D printing. The book "3D-tulostuksen suunnittelu- ja päätöksenteko-opas yrityksille" will be published in late 2016 by Teknova. It is written in Finnish.

The book is based on the results of the project and on the current knowledge of the technology. It is directed mainly at the needs of the Finnish metal industry.

In the book, the different technologies of additive manufacturing are described briefly, focusing on the main technologies for metal additive manufacturing, meaning powder-bed fusion and direct energy deposition. In addition, it gives understanding of the main application areas of additive manufacturing, how to utilize AM technology in the product development phase, and how final products can be manufactured using AM methods. The main materials for 3D printing are also listed, as well as service providers, job shops, and potential R&D partners, especially in Finland.

There are also several pilot examples of additive manufacturing. These are taken from the cases made for the DIMECC MANU companies. Finally, the future of AM is highlighted briefly.

3. Studies of large component manufacturing

The most usual type of metal additive manufacturing, powder-bed fusion (PBF), is limited by the size of the components produced. Because, in Finnish industry, there is a great need for larger products made using additive manufacturing, possibilities to avoid the size limit of PBF by joining AM components by welding were studied.

Welding is the most common joining method for metallic materials. However, there has been almost no research on welding additively manufactured components, and very little information is available on possible differences from the welding of sheet metal components.

Austenitic stainless steel components produced by powder-bed fusion were welded using the TIG method. The results showed that all the welds exhibited higher yield strength than the sheet metal welds, but at the same time the ultimate elongation was lower (see Figure 4). There was a certain effect of building direction on the properties. However, it can be concluded that arc welding (at least TIG) is a feasible method for welding additively manufactured components. In addition, welding some other materials, such as high-strength X30Mn22 steel, was studied, showing acceptable mechanical properties.

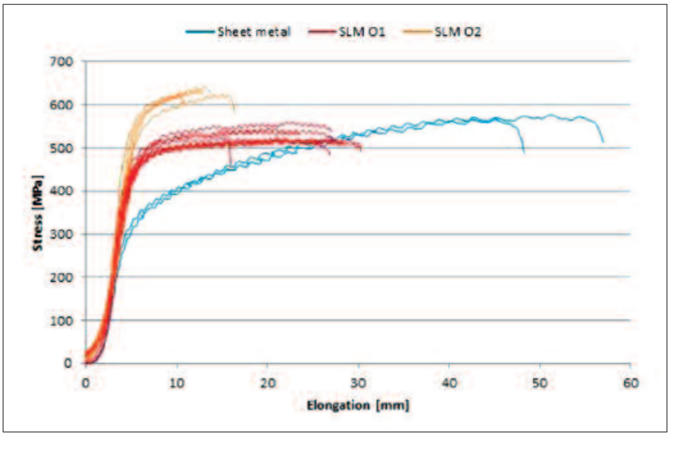


Figure 4. Stress-strain diagram of steel AISI 316L welds of an additively manufactured component

Further information

CONTACT PERSONS:

Prof. Veli Kujanpää, VTT Technical Research Centre of Finland Ltd
Prof. Jouni Partanen, Aalto University
Prof. Antti Salminen, Lappeenranta University of Technology
Prof. Eric Coatanea, Tampere University of Technology

PARTICIPANTS:

VTT Technical Research Centre of Finland Ltd
Aalto University
Lappeenranta University of Technology
Tampere University of Technology

PUBLICATIONS:

Joonas Pekkarinen, Antti Salminen, Veli Kujanpää, Laser cladding with scanning optics: Effect of scanning frequency and laser power beam density on cladding process, J. Laser Appl. 26, 032002-1 – 032002-9 (2014); http://dx.doi.org/10.2351/1.4868895.

Jorge Paredes Garibay, Jarno J.J. Kaakkunen, Raimo Penttilä, Jennifer Harris, John McIntyre, Petri Laakso and Veli Kujanpää, Rapid laser sintering of alkaline fuel cell substrates using integrating mirror, Journal of Laser Applications, Vol. 27, No S2, Feb 2015, pp. S29207-1 S29207-7.

Veli Kujanpää, Examples of industrial cases of additive manufacturing of metal parts, IIW Annual Assembly, Helsinki, 28.6–3.7.2015 IIW doc I-1226-15/IV-1256-15/XII-2252-15/212-1392-15.

Joonas Pekkarinen, Antti Salminen, Veli Kujanpää, Jarmo Ilonen, Lasse Lensu, Heikki Kälviäinen, Powder cloud behaviour in laser cladding using scanning optics, Journal of Laser Applications, 28, (2016); http://dx.doi.org/10.2351/1.4947598, 032007-1 – 032007-12.

V. Kujanpää, Research in Additive Manufacturing with the Objectives of industry, Conference "Additive Manufacturing for Aerospace, Defence & Space 2016", London, 29–31.3.2016

V. Kujanpää, A case for 3D printed metal component in injection molding tool, IIW 69th Annual Meeting, Melbourne, Australia, July 9.–15, 2016, Doc. I-1293-16.

P. Laakso, T. Riipinen, A. Laukkanen, T. Andersson, A. Jokinen, A. Revuelta, K. Ruusuvuori, Optimization and simulation of SLM process for high density H13 tool steel parts, LANE conference, 2016, to be published in Physics Procedia, 2016

Matilainen, V., Piili, H., Salminen, A., Syvänen, T. and Nyrhilä, O., Characterization of Process Efficiency Improvement in Laser Additive Manufacturing. Physics Procedia, Volume 56, Number 1, 2014, pp. 317–326

Järvinen, J-P., Matilainen, V., Li, X., Piili, H., Salminen, A., Mäkelä, I. and Nyrhilä, O., Characterization of effect of support structures in laser additive manufacturing of stainless steel. Physics Procedia, Volume 56, Number 1, 2014, pp. 72–81.

Nyamekye, P., Leino, M., Piili, H., Salminen, A., Overview of sustainability studies of CNC machining and LAM of stainless steel. Physics Procedia (2015) Vol. 78C, pp. 367–376.

Matilainen, V-P., Piili, H., Salminen, A., Nyrhilä, O., Preliminary investigation of keyhole phenomena during single layer fabrication in laser additive manufacturing of stainless steel. Physics Procedia (2015) Vol. 78C. pp. 377–387.

Piili, H., Happonen, A., Väistö, T., Venkataramanan, V., Partanen, J., Salminen, A., Cost Estimation of Laser Additive Manufacturing of Stainless Steel. Physics Procedia (2015) Vol. 78C. 388–396.

Piili, H., Happonen, A., Väistö, T., Venkatamaranan, V., Partanen, J., Salminen, A., Cost estimation of laser additive manufacturing of stainless steel, The 15th Nordic Laser Materials Processing Conference, NOLAMP 15, August 25th– 27th 2015, Lappeenranta, Finland, In peer-review process.

Nyamekye, P., Leino, M., Piili, H., Salminen, A., Supply chain in sustainability comparison studies of CNC machining and laser additive manufacturing of stainless steel, The 15th Nordic Laser Materials Processing Conference, NOLAMP 15, August 25th–27th 2015, Lappeenranta, Finland, In peer-review process.

Matilainen, V-P., Pekkarinen, J., Salminen, A., Weldability of additive manufactured stainless steel. 9th International Conference of Photonic Technologies LANE 2016, 19–22 September, 2016, Fürth, Germany, Published in: Physics Procedia 83C

Matilainen, V-P., Piili, H., Salminen, A., Syvänen, T., Nyrhilä, O., Preliminary characterization of phenomena occurring during single track fabrication in laser additive manufacturing of stainless steel, ICALEO 2014, 19–23 October, 2014, San Diego, USA.

Matilainen, V-P., Pekkarinen, J., Laitinen, V., Piili, H., Salminen, A., 3D tulostettujen metalliosien hitsaus, Hitsaustekniikka-lehti 1/2016.

Hovilehto, M., Jokinen, L., Holopainen, P., Salminen, A., Piili, H. Design of hydraulic component for additive manufacturing of stainless steel. 9th International Conference of Photonic Technologies LANE 2016 (Industrial) Lane 2016.

Matilainen, V-P., Pekkarinen, J., Laitinen, V., Piili, H., Salminen, A., Welding of Additive Manufactured Stainless Steel Parts, Submitted to be published in Welding In the World,

Holmström J, Holweg M, Khajavi SH, Partanen J. The direct digital manufacturing (r)evolution: definition of a research agenda. Oper Manag Res [Internet]. Operations Management Research; 2016;9(1–2):1–10. Available from: http://dx.doi.org/10.1007/s12063-016-0106-z.

Khajavi SH, Partanen J, Holmström J, Tuomi J. Risk reduction in new product launch: A hybrid approach combining direct digital and tool-based manufacturing. Comput Ind. 2015;74:29–42.

Syrjälä, Kai: New possibilities of metal 3D printing for industry. Hitsaustekniikka-lehti December 2014.

THESES:

Matilainen, V., Improvement of process efficiency in laser additive manufacturing of stainless steel, Master of Science Thesis, Lappeenranta University of Technology, 2014, 103 p.

Nyamekye, P., Environmental and economical analysis of powder bed fusion, Master of Science Thesis, Lappeenranta University of Technology, 2015, 111 p.

Laitinen, V., Weldability of laser additive manufactured stainless steel 316L components sheets to conventionally manufactured sheet metal, Master of Science Thesis, Lappeenranta University of Technology (to be completed 6/2015).

Li, X., Characterization of effect of different support structures in laser additive manufacturing of stainless steel, Master of Science Thesis, Lappeenranta University of Technology, 2014, 99 p.

Emmi Välimäki, Modelling, simulation and validation of CMT technology: An application for additive manufacturing, MSc thesis, 2016, Tampere University of Technology.

Mielonen M. Improving production efficiency of injection molding process by utilization of laser melted tool inserts with conformal cooling. Master of Science Thesis, Aalto University; 2016.

TASK 2 Visualization of Sustainability Key Performance Indicators 2013–2015

Summary of the project's motivation and achievements

The aim of the subproject was to develop a process model to identify and implement relevant sustainability key performance indicators (KPIs), and to link the measurement results to performance improvement and management.

Sustainability is more than just being green or nature-friendly. Sustainability has three pillars: economic, social, and environmental aspects. The developed Sustainability Measurement Framework (see Figure 1) is based on Six Sigma and can be adapted to all product life-cycle phases.

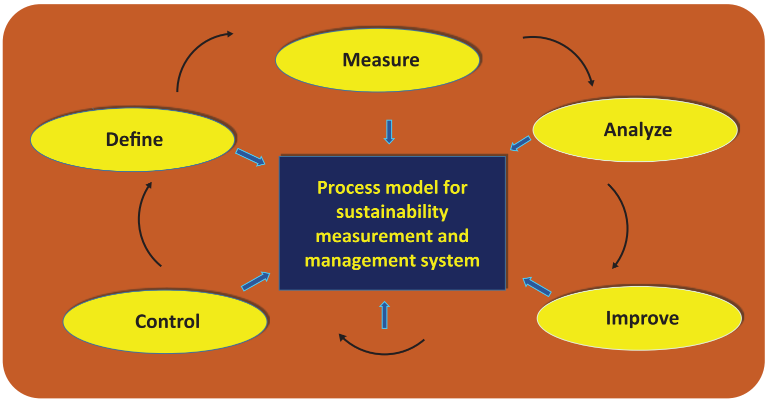


Figure 1. Process model main steps in developing and implementing a sustainability measurement and management system

A general overview, as well as research needs on sustainability in manufacturing companies in Finland, was created using Internet questionnaires, company interviews, and workshops. The focus in the research was on sustainable manufacturing and product development. This work should also be extended to a manufacturing and supply network level.

The final report of the subproject shows the concept of the Sustainability Measurement Framework (see Figure 2). The aim is to use sustainability performance indicators and data to create a competitive advantage. Some examples are shown on how to integrate sustainability aspects in digital manufacturing tools. The subproject final report also specifies selected sources for further information on sustainability. Many organizations are providing handbooks and training materials for companies, on how sustainability can be taken into consideration in business.

The Sustainability Measurement Framework conceptual model was tested with one industrial feasibility case. This subproject included extensive international dissemination, with research publications and research reports targeted at DIMECC MANU program stakeholders.

KEYWORDS: *Sustainability measurement in manufacturing industry, sustainable development, sustainable manufacturing, sustainability key performance indicators.*

Key results and impacts

Even though general definitions and concepts of sustainability exist, typically only the environmental pillar of sustainability is highlighted. More practical examples of the two other dimensions of sustainability, as well as success stories, are also needed in the manufacturing industry. For business benefits, sustainability-driven business models are required to specify sustainability changes concretely.

Sustainability started with the concept of being green, becoming more environmentally friendly, and paying more attention to conserving our planet's resources. Now sustainability has become much more than that. Sustainability has three pillars: economic, social, and environmental aspects. Focusing solely on environmental concerns while using the term sustainability is both misleading and improper, as this concentration on one pillar of sustainability ignores the two other pillars, and can lead to designs that are not economical to produce, or that contain the potential for negative social impacts.

The number of regulations that are related to sustainability has been steadily growing, presenting new legal obligations for industry. Enterprises are also becoming increasingly aware of the importance of being able to credibly present facts about the sustainability of their performance to the public, which is increasingly aware of its importance.

The focus of engineering design on achieving a superior product, process, or service, from the currently prevalent point of view of functional and economic factors, is now shifting toward sustainable design. Sustainability-related issues are increasingly important in business decision-making. Examples of the drivers of this development are:

- Cost savings, resource efficiency
- Society-set regulations, directives, standards
- Customer requirements, business reputation
- Organization and others giving support

Sustainability requires simultaneous consideration of the economic, environmental, and social implications associated with the production and delivery of goods. Sustainable development and manufacturing relies on descriptive metrics, advanced decision-making, and a policy for implementation, evaluation, and feedback.

The path toward sustainability is proving a struggle for Finnish manufacturing companies. Sustainability is a viable business strategy that takes into account economic considerations, governmental issues, and strongly voiced opinions from customers and stakeholders.

The concept of sustainability performance indicators, reporting, and improvement, "Sustainability Measurement Framework for Finnish manufacturing companies", has been developed, published, and benchmarked in international conferences, including journal publication. One feasibility test case was evaluated with the LeanMES project. The research partners are available to support the Finnish manufacturing industry in its steps toward sustainable business.

Further information

CONTACT PERSONS:

Juhani Heilala, VTT Technical Research Centre of Finland Ltd
Saija Vatanen, VTT Technical Research Centre of Finland Ltd
Eeva Järvenpää, Tampere University of Technology (TUT)

PARTICIPANTS:

Research and development work was carried out at VTT Technical Research Centre of Finland Ltd (VTT) and Tampere University of Technology (TUT), in collaboration with DIMECC MANU program partners.

The subproject included extensive international dissemination, with five research publications and research reports targeted at DIMECC MANU program stakeholders as well as a general audience.

PUBLIC REPORTS AND PUBLICATIONS:

1. Heilala Juhani (2015), Kestävän kehityksen mittaaminen valmistavassa kappaletavarateollisuudessa. Automaatioväylä 5/2015.
2. Juhani Heilala, Marja Myllysilta, Saija Vatanen, Eeva Järvenpää, Kai Syrjälä (2015), The Concept For Sustainability Performance Indicators, Reporting And Improvement. Subproject final report. Available at http://hightech.fimecc.com/results/final-report-fimecc-manu-subproject-visualization-of-sustainability-key-performance-indicators.
3. Myllysilta, M.; Vatanen, S.; Heilala, J. (2015) Ekotehokkuuden arvioinnilla tukea päätöksentekoon – Opas arviointimenetelmästä yrityksille. FIMECC MANU Report 2015.

4. Mikko Koho, Mikko Tapaninaho, Eeva Järvenpää, Minna Lanz, Juhani Heilala (2015). Sustainability Performance Measurement and Management: Process Model. FAIM2015, June 2015.

5. Mikko Koho, Mikko Tapaninaho, Juhani Heilala, Seppo Torvinen (2015). Towards a Concept for Realizing Sustainability in the Manufacturing Industry (JIPE SDM14 Special Issue), Journal of Industrial and Production Engineering (earlier known as The Journal of the Chinese Institute of Industrial Engineers (JCIIE)). Published online: 12 Jan 2015. DOI: 10.1080/21681015.2014.1000402.

6. Tapaninaho, Mikko; Koho, Mikko; Pihkola, Hanna; Heilala, Juhani (2014). Developing A Concept For Sustainability Indicators And Reporting Systems For Finnish Manufacturing Industry. SPS 2014.September 2014. Available at http://conferences.chalmers.se/index.php/SPS/SPS14/paper/viewFile/1690/363.

7. Koho, Mikko; Tapaninaho, Mikko; Heilala, Juhani; Torvinen, Seppo (2014). Measures and a Concept for Realizing Sustainability in the Manufacturing Industry. SDM 2014, April 2014.

8. Tapaninaho, Mikko, Koho, Mikko, Nylund, Hasse, Heilala, Juhani, Torvinen, Seppo (2013). Sustainability Performance Indicators for Supporting the Realization of Sustainable and Energy-Efficient Manufacturing. FAIM 2013, June 2013.

Task 3 Smart factory 2015–2016

Summary of the project's motivation and achievements

Building common understanding of product, process and information flow from design to realization of products under DIMECC MANU framework. The work will be done in five workshops, where all DIMECC MANU subprojects will contribute their specific knowledge. The 6th workshop in the end of 3rd period will result MANU's common theoretical Framework and will provide DIMECC MANU technological and scientific leap.

The common workshops created the vision of "Smart Factory" pilots that will integrate productive design, supply chain management, factory control and work systems. The goal is to show how smartly used digital technologies can increase quality, cost-efficiency and bring added value to the Finnish metal and manufacturing sector.

Smart Factory Handbook (will be published in spring 2017) contains following chapters:

I. Productive Design: Review of new technologies and best practices that will shorten the design process time, optimize different design parameters and control information in post-design life-cycle phases

II. Productive Supply Chain: Review of technologies, best practices and tools for simulation and analysis of supply chain regarding on how different factors will affect to the competitiveness.

III. Productive Factory: Review of planning, simulation, analysis and control tools (possibilities and constraints) that will fit to lot-size-1 production.

IV. Productive Work Systems: Review of different leading, guiding and coaching methods that can support, create and benefit from physical and digital work environments, human-machine collaboration and Human-in-the-Loop.

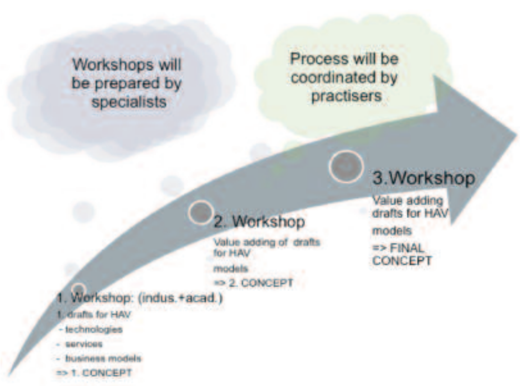


Figure 1.

The objectives of the Smart Factory task was to enhance cooperation between all DIMECC MANU projects and build common understanding of product, process and information flow from design to realization of products under DIMECC MANU framework. The work was done in five workshops, where all DIMECC MANU sub-projects contributed their specific knowledge. In collaboration with the common workshops the aim was to build Smart Factory pilots to show how smartly used digital technologies can increase quality, cost-efficiency and bring added value to the Finnish metal and manufacturing sector. The pilots were implemented in production and supply chain simulations in two manufacturing companies.

State of the art

Today's business, especially manufacturing, environments are characterized by rapidly changing requirements in terms of customized products, unpredictable demand, small batch sizes and very limited access to actual operational data. The finding is that in relation to digitalization a lot of companies could have gained profits from new products via exports and incoming orders if investments and up-date of production concepts were decided in time.

- The manufacturing systems and networks should adapt rapidly to these frequent changes and disturbances that cannot be foreseen. Unfortunately, the readiness to adopt digitalization in this field is stagnating. The ICT tools used in many of the companies currently used in design, manufacturing, operation control and maintenance have been created for the old markets where the mass-customization was a norm.
- One of the greatest challenges lay in ICT solutions, which have been developed as stand-alone systems. Connectivity to other systems outside the immediate application domain has not been realized.
- The digital information flow desperately needed today, does not exist yet. This is one of the barriers for export business in many companies. The operability and speed of a manufacturing network slows down, and costs of operation increase dramatically leading to low cost-efficiency in Finland.

For example the data from the manufacturing systems is heterogeneous: the quantities might differ, there is no shared structure, and even the lowest-level bit structure can differ. Besides, the setting in a factory is not stable: machines are installed, removed and updated. In addition, the amount of data generated by the manufacturing systems grows fast with increasing number of sensors and data logging from the interconnected systems. Because of these problems the operational data is still not collected efficiently in companies. Moreover, even if it is collected, it's not processed and used in such way that Finnish companies could take advantage of digital quality management, big data and industrial Internet possibilities.

Smart Factory concept – Generation of new ideas

The generation of ideas for the Smart Factory concept started with the industrial workshops. The objectives of the first workshop were to form a common understanding of the present state of manufacturing company's process digitalization including the current technology and its usage in companies. Another objective was to form a common understanding of possibilities of digitalization in manufacturing company in time spans of 0–3, 3–5 and 5–10 years. Digitalization current state and future possibilities were considered in three areas: sales and tendering process, design process and order delivery process.

1. **Digitalizing the information flow:** In the current state the main issues was related to the facts that there is many different software in use and lots of manual work done in different stages. The main possibilities in tendering and design process were heading gradually from software integrations/reduction and real time data to modular product structure and digital sales configurator. In production side the development path were thought to start from re-planning the material flows and start to gathering real time data. In 3–5 year time span there were planned among others PDM/CAD system integration to the production machines. Finally in the 5–10 year time span there was robotization and automatization of production as well as digital logistics planning and simulation of installation process.
2. **Optimization on different levels:** The objective of optimization workshop was to find new targets where optimization can be used. The optimization means finding the optimal solution to the problem by analysing facts. By analysing large amount of data and using specific optimization algorithms, excellent results are got for example from structure design and cost optimization. The benefits of optimization includes transparency through identified objectives, better results since a computer can check larger search space rather than a few candidate designs and faster design process. In the workshop 21 possible targets for optimization were found from participants business including among others production control, automatic warehouse, product modularization, resource efficiency, container ship load maximization and material waste optimization in machine workshop. Five of those were processed further by defining objectives, design variables and constraints of the problems. In the production control optimization the

objective was defined as cutting throughput time; the parameters were production batch size, control methods and amount of work shifts; and constrain is the need to keep current system and layout. This same production control case was also further processed in another Smart Factory pilot.

3. **Digital Information Flows and System Architecture:** The objectives of the third workshop was to clarify bottlenecks of systematic work and flow of information in supply chain, clarify possibilities of configuration in order delivery process and create a roadmap to develop information flow in supply chain. In the case company configurable products have affected so far only design part in order delivery process. Two different areas were considered: sales-design interface and design-purchasing interface. Here again the main challenges in current state are related to use of many different software and manual work stages. Also handling the revisions during the order-delivery process is sometimes challenging. In sales-design interface the main development work were planned to focus on sales configurator and integrating that to existing design configurator. In the design-purchasing interface the development path starts for example from reducing use of excel files and taking partners along to the development work. The long term goal is one digital company where also partners and subcontractors are deeply integrated.
4. **Tracking and Tracing in Production:** The objectives of the fourth workshop were to build common knowledge of state-of-the-art tracking and tracing methods and also the future goals in that area. Third objective was to build a roadmap in ten year time span. Tracing is mandatory in some business areas nowadays but the benefits to manufacturing in general are essential. Knowing where the materials come from and what have been done to the product during production process and in use, is beneficial to quality control and essential information for the end user of the product. A company could for example sell digital fingerprint of products as separate extra information to the customer. By adding sensors to the product, for example the end use conditions can be monitored, which could be also sold as an extra service. Tracking the material real time in production helps for example significantly production control and is essential addition to sensors and machine vision in highly automated production. The methods for tracking and tracing discussed in the workshop included RFID tags, bar codes and gateways in production.
5. **Quality Control and Tracing by Digital Means:** Fifth workshop was held in Mapvision Ltd. In the workshop they introduced their state-of-the-art machine vision aided quality control and tracing methods. Their innovative measuring cell uses tens of machine vision cameras to meas-

ure all of the parts in customer's production line. That kind of cell is used for example in car industry to measure weld seam quality and adjust the welding process in-line by using the measurement data. The case example showed the complete traceability of the operations can indeed be achieved.

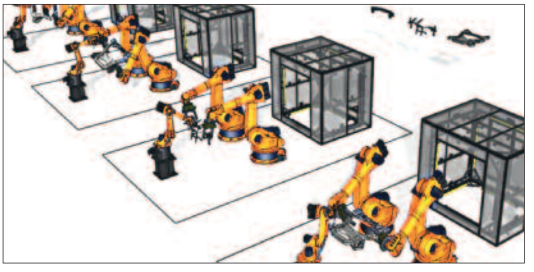


Figure 2. **Intelligent robot assisted welding cell**

Based on the workshop input and international benchmarking the following aims were identified to be in the core of the Smart Factory concept. The Smart Factory concept aims developing a concept where the information flow is ensured throughout the life-cycle phases the product and the production system may have. At the core of the Smart Factory concept there are following high-level targets:

- **Digital twins of the product and manufacturing system** that allows as realistic (and relevant) as possible simulations targeting to future scenarios to be created and updated.
- **Context-aware systems**, as a system is always part of a wider system. The entities are communicating with other entities, whether they are part of the same enterprise or existing in the manufacturing network.
- **Support for system level adaptation** consisting of (semi)autonomous and co-operative manufacturing entities, capable of fulfilling their own tasks, and of operating together with other entities.
- **Knowledge-based manufacturing entities**, capable of developing and learning from the actions, constantly updating their skill and knowledge for future operations.
- **Service-oriented activities**, where the communication between the entities is seen as services. Only needed information is included in the services and the skills and knowledge are kept as the autonomy of the entities.
- **Formally presented product and manufacturing system information** ensuring that the information and knowledge exists only once in a formal and up-to-date form available and understandable to all related parties.

The Smart Factory information system architecture accomplishing the efficiency and digitalization goals, comprises four levels, see Figure 3. The first one is the shop floor level, which represents the whole production environment with its respective resources. The generated information, due to the production process, comprehends of energy related sensory data. The information is then analyzed, reasoned and processed in the second level, the data level, and are thus made usable for planning, decision-making and control purposes accomplished on the third level, the planning and adaptation level. On the fourth level, the business management level, the KPI information is used to aid in the business decision-making. A schematic draft of the system architecture is presented in the following.

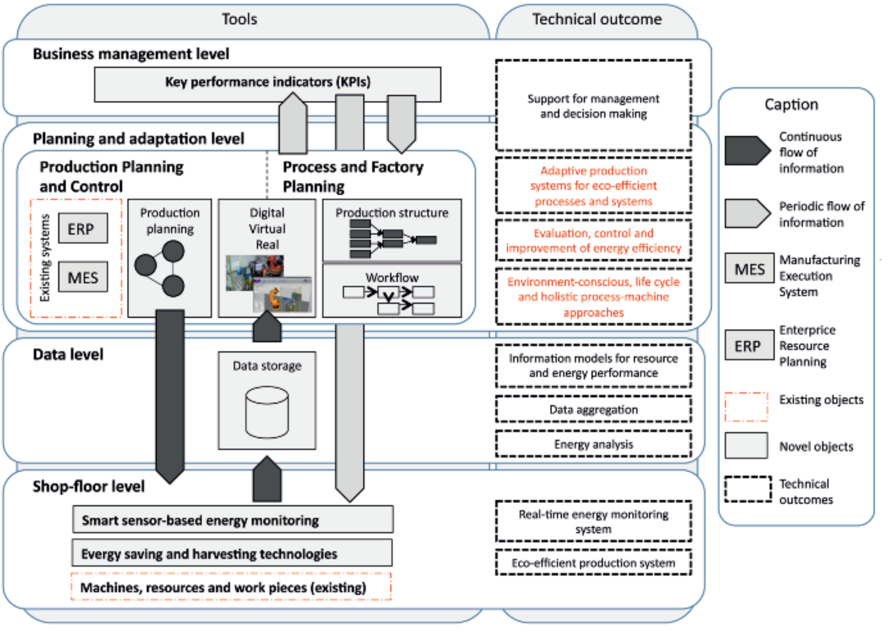


Figure 3. **Levels of the Smart Factory concept**

Smart Factory pilots

The pilot cases are simulation studies for smart industrial value chain. Both of them are implemented using combination of spreadsheet and discrete-event simulation software packages. The pilot cases are modeled using Siemens Tecnomatix Plant Simulation software. Simulation models can be built both in 2D- and 3D-environments. Simulation results can be viewed inside the software and the data can also be exported to generate the results in different software e.g. in MS Excel.

The case Ruukki is a simulation study for steel truss process. The process consists of material storage, blasting and sawing, assembly welding, surface treatment and storage area of finished products. Between each phase of the process is a buffer area for work in process. Some of the parts are subcontracted because they need manufacturing methods that doesn't exist in the main factory. The aim of the case is to observe bottlenecks and throughput times of the process as well as experimenting different scenarios for future operation principles of the factory. Currently the gathering of the needed input data for the simulation model is an ongoing process. Simulation experiments can be done only after the input data is implemented into the simulation model.

The case Katsa is a simulation study for part manufacturing process of gearwheels, gear shafts, gear rings and gear couplings as well as slewing bearings. The process includes several facilities in different locations, subcontracting locations, and logistics between the locations. The variation of the parts is large and they have numerous different value chains. The main goal is experimenting different production planning and control principles. These include applying theory of constraints management paradigm for key resources, dedicating selected resources for specific part families, and finding bottlenecks of the value chains. Also in this case, the gathering of the input data is currently in process.

The pilot cases are somewhat different but both of them focus on improving the manufacturing activities within a company. Similar to both of the cases is to identify bottlenecks and to find means to avoid them. Also the main areas of the pilot cases are similar. Figure 4 presents those main areas of the pilot cases.

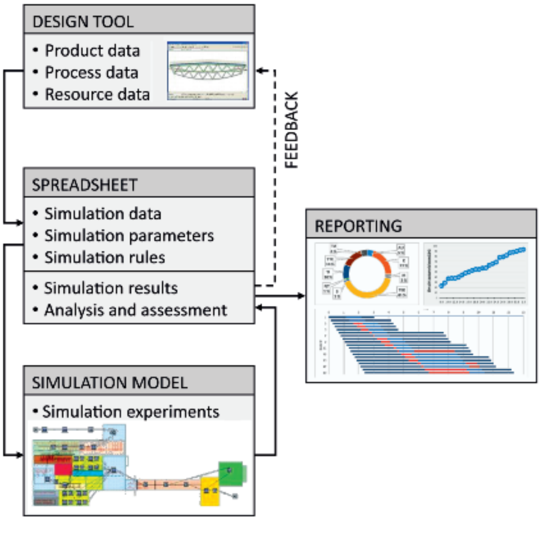


Figure 4. Main areas of the pilot cases

The design tool is a specific tool used in the case Ruukki and it was developed during the DIMECC MANU program. It represents the source of information used in the building of the simulation model. In the Katsa case, similar information was gathered from enterprise resource planning (ERP) software. In both cases the required information included product, process, and resource data. The required information is built around the process data, which means the flow of the products i.e. the process chain in the modeled manufacturing system. The product data includes e.g. the product portfolio used in the simulation experiments and some product specific parameters. The resource data holds processing times and capacity, and in some resources also, for example, setup times.

The gathered product, process, and resource data is then stored and manipulated in independent software that in the pilot cases was MS Excel due to its wide usage in companies. This data was used for simulation data and rules to construct the structure and behavior of the simulation model. Simulation parameters were used to create different simulation scenarios. Examples of the simulation parameters used in the case Ruukki were:

- Production program – altering the start dates of the products.
- Production batch – altering the number of products in the batches.
- Working time – selecting 1–3 shifts for each resource individually. One shift represents eight hours while three shifts covers a whole day.
- Number of resources – defining the number of parallel resources for each resource individually.

Figure 5 presents an overview of the simulation model of case Ruukki. The objects represent resources and storages while the different functional areas are color-coded. The simulation model is built on 2D factory layout. Due to the aims of the pilot case, realistic looking 3D-graphics were not considered to bring more value to the simulation experiments.

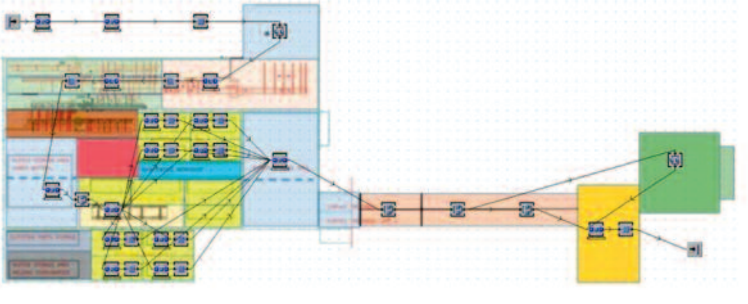


Figure 5. Illustration of the case Ruukki simulation model

Several simulation runs were conducted altering the simulation parameters. After each simulation run, the results were analyzed and their applicability was assessed. The simulation model indicated what is the effect of altering a simulation parameter but doesn't necessarily tell how the actual change could be implemented. Figure 6 shows an example of the results from a simulation experiment. In this example the production of two batches of 10 products were simulated with certain parameters of parallel resource and number of shifts. The bar shows the total throughput time of the products and the different colors indicate how long the product has spent in a certain part of the factory.

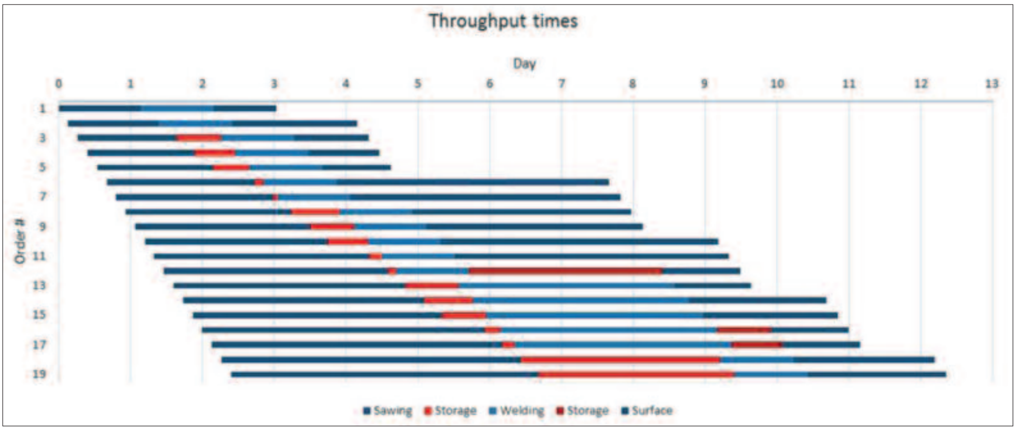


Figure 6. **Example of simulation results**

At the end of the simulation study the results were reported for a bigger audience. Selected results from the different simulation experiments were selected in that they clearly show the effect of altering the simulation parameters.

Further information

CONTACT PERSONS:

Muuta: Kai Syrjälä, Kaidoc Oy

Minna Lanz, Tampere University of Technology

PARTICIPANTS:

TUT, VTT, Kaidoc Oy, Ruukki, Katsa, MacGregor, Mapvision, Fastems, Raute.

DIMECC Oy
Korkeakoulunkatu 7, 33720 Tampere, Finland
DIMECC Factory, Oulu
DIMECC Factory, Tampere
DIMECC Factory, Turku
DIMECC Factory, Espoo

DIMECC Program
MANU

WWW.DIMECC.COM

ISBN 978-952-238-176-7
978-952-238-177-4 (pdf)
DIMECC Publication series
ISSN 2342-2696 (online)

9 789522 381767