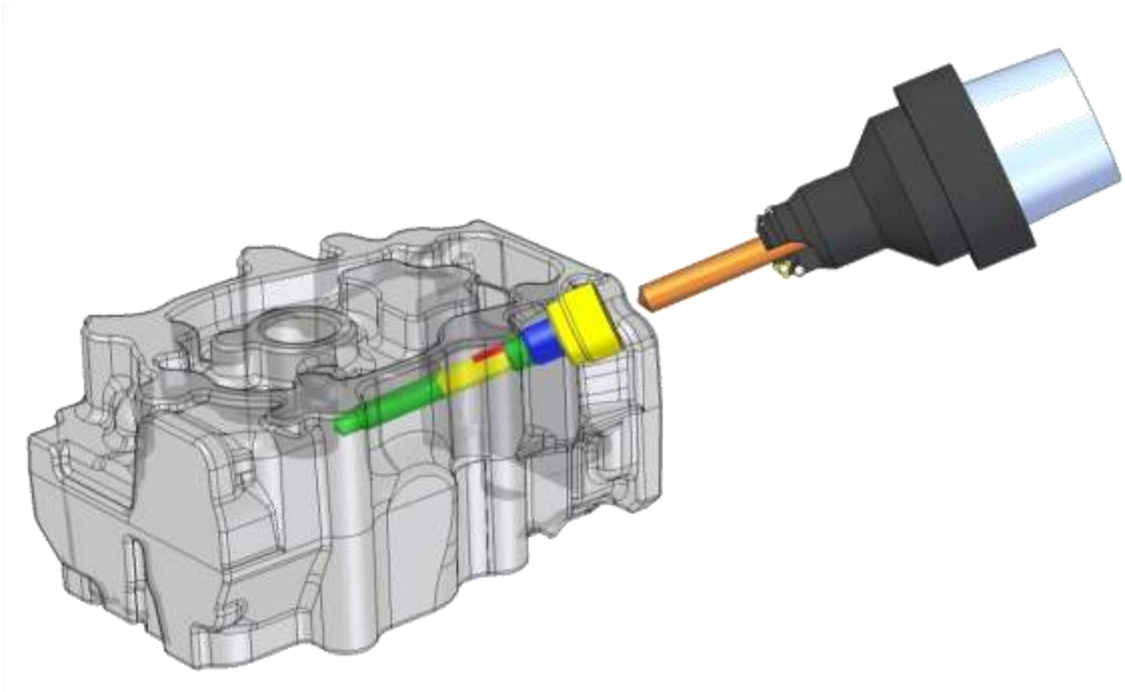
Feature based operation planning



Project within FFI - Sustainable Production Technology

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Content

1. Executive summary

This project aimed to create new knowledge and develop technologies that enable Swedish automotive industry to competitively pursue knowledge-based production in Sweden and thus help to maintain a competitive vehicle production in Sweden. An important part of this is to promote the development of efficient computer-aided process planning, which is a very important process in a manufacturing company where the purpose of process planning is to find the most productive and efficient manufacturing solution possible. The scope of process planning is very wide, spanning from conceptual planning to detailed operation planning. This project has focused on model-driven feature based operation planning. With model-driven means an approach in which you use digitally represented models of products, blanks, fixtures, tools, machine tools, etc. that provide information on materials, features, manufacturing requirements and tolerances etc. A basic idea of the model-driven approach is that the product can be described as consisting of different features (planes, holes, grooves, etc.) for which there are various methods of manufacturing them. The method that is most appropriate depends partly on the manufacturing requirements and tolerances that are specified, but also on the process planner´s experience and current practice at the manufacturing company. A basic objective of the model-driven approach is using computer technology and software for; creation, visualization and interaction with models, to support human knowledge and expertise. During the project, research was performed in collaboration with industry partners and system suppliers to explore the applicability of model-driven operation planning based on industry needs, available software for operation planning, and international standards for information modeling of product, process and resource representations. Industry needs have been identified through study visits and joint workshops. The system supplier partners in the project have, in workshops and cooperation with the participating manufacturing companies, demonstrated what their process planning applications are capable of. Based on these studies and observations, ideas and suggested implementations were proposed and discussed at regular joint meetings. With industry feedback, these suggestions and ideas have then evolved into several prototype applications for demonstration of model-driven operation planning. The project has also collaborated with the FFI projects; Digital Factory Building Blocks and Robust Machining. In addition, the project has participated in international information modeling, in a collaboration to which the project has delivered significant contributions in the field of kinematic representation. The results of this project are in the long term significant contributions to increase productivity and quality in operation planning and the manufacturing processes. The close collaboration between research and industry has strengthened the good relations between Swedish production research and Swedish automotive industry. Through various demonstrations, the project has communicated the possible benefits of a model-driven approach for operation planning for industry. It has shown that it is possible to implement the demonstrated functionality using system neutral and international standards for information modeling. Most of these demonstrations have attracted international attention and have been recognized as important contributions in the area of Virtual Manufacturing. Swedish production

research in information modeling for industrial applications has from an international perspective a good position. To maintain this position, it is important to continue the research in model-driven process planning and a suitable area to continue in is the Production Part Approval Process (PPAP). The purpose of PPAP is to confirm that a supplier has properly understood all the design and specification requirements for the components they supply, and that their manufacturing process has the capability of consistently delivering products that comply with those requirements. PPAP is used in the automotive supply chain to establish confidence in component suppliers and their production processes. However, current PPAP is labor-intensive where process planners have to spend valuable time on non-value adding work in creating all the necessary documents required in PPAP. Replacing current labor-intensive and document-based PPAP with a model based ditto would streamline the current PPAP and increase productivity in both production and the preparation of production.

2. Background

For competitive production of innovative, environment sustainable and safe products, efficient operation planning is required. The objective with process planning is to find the most productive manufacturing solution and the scope is huge as process planning spans from generic or conceptual planning (finding suitable technology for producing a feature, a part or a product) to detailed operation planning (defining operations, determining detailed process parameters and required tools, defining setups and operation sequence, resources etc.). In computer aided manufacturing (CAM) the feature concept has been seen as a corner stone to realize semantic machining. In design and manufacturing, features is a way to give semantic context to component geometry. With defined features such as hole, pocket, chamfer, thread and slot, semantically expressed in the design model, it is possible to relate to machining processes that realize the design intentions. To realize design intention, features are detailed with dimensions, tolerances and other manufacturing requirements and constraints. By utilizing features, design and manufacturing knowledge can be captured, represented and communicated. Efficient feedback of the manufacturing process, maintenance of manufacturing knowledge and continuous improvements are key components to gain competitiveness over time (*Figure 1*). Using standardized processes is a proven method to achieve high repeatability and predictability of the machining process and it is also a base for further improvements. Proper management of company specific features and their related machining processes supports preservation and development of intellectual property. With more efficient tools for computer aided manufacturing, more effort can be put into the value adding and intellectual work within operation planning for production using sustainable technology.

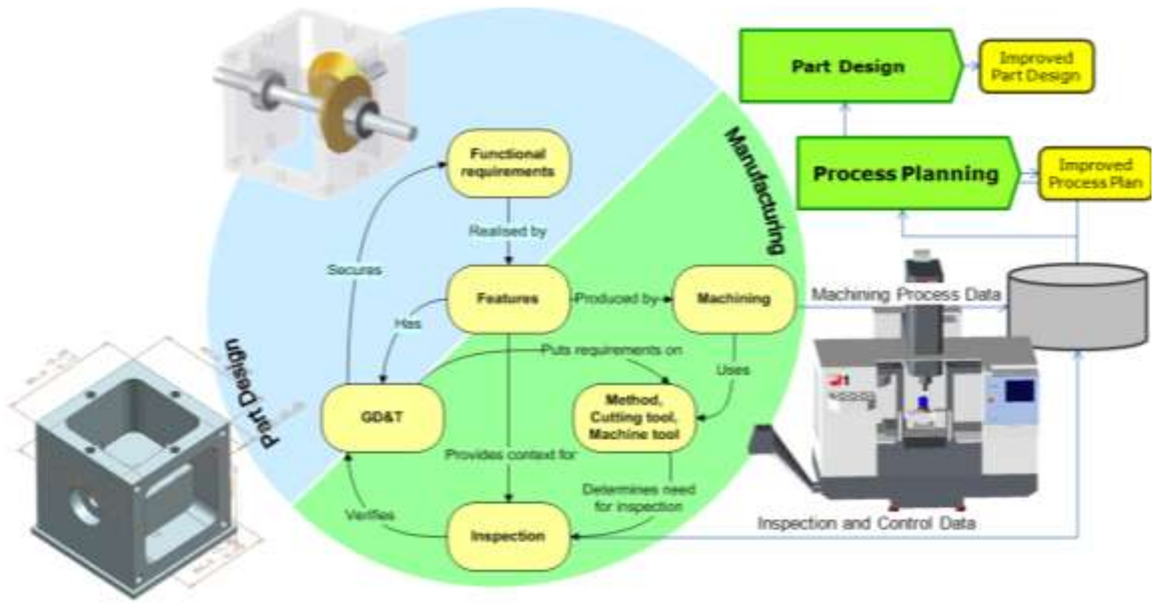

Figure 1: Feature, a cornerstone in semantic machining

3. Objective

Figure 2: Fundaments of model-driven operation planning

The long term goal with the project has been to contribute to create the foundation for flexible, sustainable and competitive manufacturing of today´s and tomorrow's environmentally sustainable automotive components and products in Sweden, in which efficient and qualitative operation planning is a key activity. As indicated by the name, the project has a strong emphasis on features, a fundamental concept in model-driven operation planning. To remain competitive on a global market, Swedish automotive companies rely on technology as well as on skilled and creative employees, which truly are a vital asset in any manufacturing company. The model-driven approach aims to support human capabilities of skilled process planners by using computer software for modeling; creation, visualization and interaction (*Figure 2*). Product- and blank models that provide information about machining features, material properties, dimensions and tolerances, surface textures etc., are essential in the model-driven approach. Further, resource models such as machine-tool, cutting tool, fixture and measuring equipment models, consistent with real system behaviour, enable simulation and verification of machining operations. All together this contributes to shorten lead-time in the introduction of new products, and shorten ramp-up time by usage of virtual manufacturing. By making first parts right, not only lead-time and ramp-up time will be shortened, but environmental impact in the manufacturing process will also be reduced.

4. Project realization

During the project the research team has in collaboration with industry partners and system suppliers investigated the applicability of model driven operation planning by studying industry needs, process planning software capability, and international information modeling standards for product, process and resource representation. System neutral information standards make manufacturing information transparent, decreases non-value adding rework and secure data longevity. Furthermore, as it isn't expected that all partners in collaborative manufacturing will have the same type of computer systems, utilization of international standards and open CADCAM and CNC systems prior to proprietary formats has been a strategic approach within the project to reach the stated objectives.

4.1 Project structure – Work packages

The project has been organized in eight different work packages (WP) each one (except for WP 1) categorized (*Figure 3*) as either being mainly oriented towards research, development or knowledge transfer.

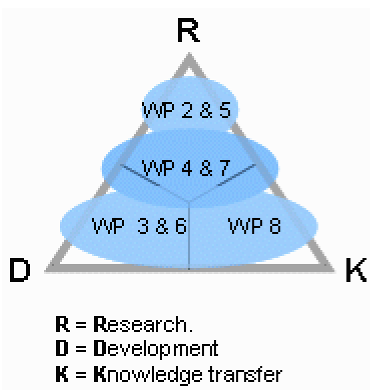

Figure 3: The different work packages of the project

WP 1: Project coordination and result dissemination

The aim of WP 1 was to manage the project and disseminate project results including workshops, meetings, progress reports, publications and project reports.

WP 2: Product modelling

The aim of WP 2 was to study the ISO 10303 standard for product data representation, especially the ways in which essential technical requirements, functional features and surfaces, dimensions and tolerances, surface and material properties, manufacturing information and notes etc., can be represented by the standard.

WP 3: Manufacturing feature library

The aim of WP 3 was to investigate and study principles for defining company specific product features and how to relate them to machining processes and cutting tools using available commercial state-of-the-art software for feature based operation planning.

WP 4: Manufacturing rules for decision support

The aim of WP 4 was to evaluate principles and interaction methods for defining rules utilizing appropriate terminology, concept and context definitions and investigating state of the art for rule management in commercial systems for operation planning.

WP 5: Manufacturing ontology

The aim of WP 5 was to develop methods to create, represent and apply company specific concepts and corresponding terminology in operation planning, and investigating how to apply ontologies for different domains e.g. product models, features, machining processes and manufacturing resources utilized in rules and operation planning.

WP 6: Information platform for operation planning

The aim of WP 6 was to develop software applications that, based on the results from the research oriented work packages, can be used to demonstrate model-driven feature based operation planning utilizing product- and resource models (machine tools, cutting tools, fixtures etc)

WP 7: Model driven operation planning

The aim of WP 7 was to demonstrate possibilities enabled by model driven operation planning for machining cells and machining lines to improve productivity and product quality.

WP 8: Demonstrator

The aim of WP 8 was to evaluate available software for process planning and to demonstrate model-driven operation planning on real products which are manufactured by the different industry partners in the project.

4.2 Methodology

The basic methodology for the work within in the project has been to study industry needs, which for instance is implicitly reflected in the different demonstrators (WP 8), and based on these studies decide what type of actions should be performed by the researchers. Within the project there has been regular joint meetings and workshops where industry needs have been discussed and research ideas and propositions have been presented. Based on industry feedback these ideas have then been further developed. The researchers have developed prototype software applications to demonstrate model-driven process planning. In addition, the software supplier partners in the project have demonstrated their software´s capability at a couple of workshops. The software suppliers have also had some collaboration with industry where the objectives have been to investigate industry need and to validate the capability of their products with respect to industry need. Project ideas and results have also been presented and discussed within the international collaboration of ISO/TC 184/SC 4 and the STEP manufacturing community.

4.3 Project collaboration

During the project period there has been collaboration and joint work within the area of machine tool modeling with the two FFI projects Digital Factory Building Blocks and Robust Machining. In addition, there has also been international collaboration regarding information modeling within ISO/TC 184/SC 4 where the project for instance has delivered important contributions within the area of kinematic representation using ISO 10303. The project has also collaborated with Boeing and NIST regarding model-based machine tool accuracy prediction. The results from this collaboration were presented as a machining demonstration at the international ISO/TC 184/SC 4 meeting held in Stockholm in June 2012.

5. Results and deliverables

Besides the more generally formulated FFI-goals this project aimed to fulfill, a number of specific goals, or deliveries, where formulated for each work package. This section briefly outlines the most important project results while remaining project deliveries as a whole are described more fully in the project´s separate technical report. As described in Section *4.1 - Project structure – Work packages*, the work packages were categorized as either being more oriented towards research, development or dissemination of knowledge. Naturally, the results of the work packages that focus on development and dissemination depend of the results from the research oriented work packages. Other factors that have influenced the actual result is the number of dependencies between different actors and it has been harder to fulfill specified goals if one or several involved actors have been unable to contribute as planned. During the project implementation, two large recessions has also hit the world economy and as the participating companies all operate on a global market these recessions have influenced their ability to participate in the project. Another challenge is that the different companies have their own proven way of working which available CAM applications are not easily adapted to. Additional challenges the project has faced are organizational changes within the participating companies, changes which in some cases led to a loss of individuals who had key positions in both the company and the project, and experts who had their task within the company altered, thus also affecting their continued participation in the project. Generally speaking, the project has been most successful in the work packages where the researchers have been able to work quite independently. Important result to mention here is of course the work within WP 2 – Product modeling which has resulted in a number of publications and a doctoral thesis. In a joint work with FFI project Digital Factory Building Blocks the research team at KTH, in collaboration with AB Volvo, demonstrated machine tool model exchange via STEP (*Figure 4*). In this demonstration a machine tool with defined kinematics was modeled in Siemens NX 7 and exported to STEP, then imported in to Dassault Catia V5 where the machine tool model and its kinematics could be edited as any ordinary Catia file. The machine tool model from Catia was then re-exported to STEP format and used for machine simulation of a STEP-NC program in the ST-Machine, STEP-NC browser from STEP Tools Inc. This demonstration was internationally recognized as an important contribution within the field of virtual manufacturing. It is worth mentioning that the project´s collaboration within ISO/TC 184/SC 4 has contributed to make Sweden and its manufacturing research become internationally well known and respected. Parts of the research results of the project were compiled into a large demonstrator, held at KTH during the ISO/TC 184/SC 4 meeting in Stockholm in June 2012. There, in the XPRES lab, the research group demonstrated machine tool accuracy prediction (*Figure 5*). In this demonstration a forged blank for a Scania crown wheel was machined in an old machining center which was expected to demonstrate significant deviations in terms of position accuracy during machining due to wear. Prior to the demo, the actual position of

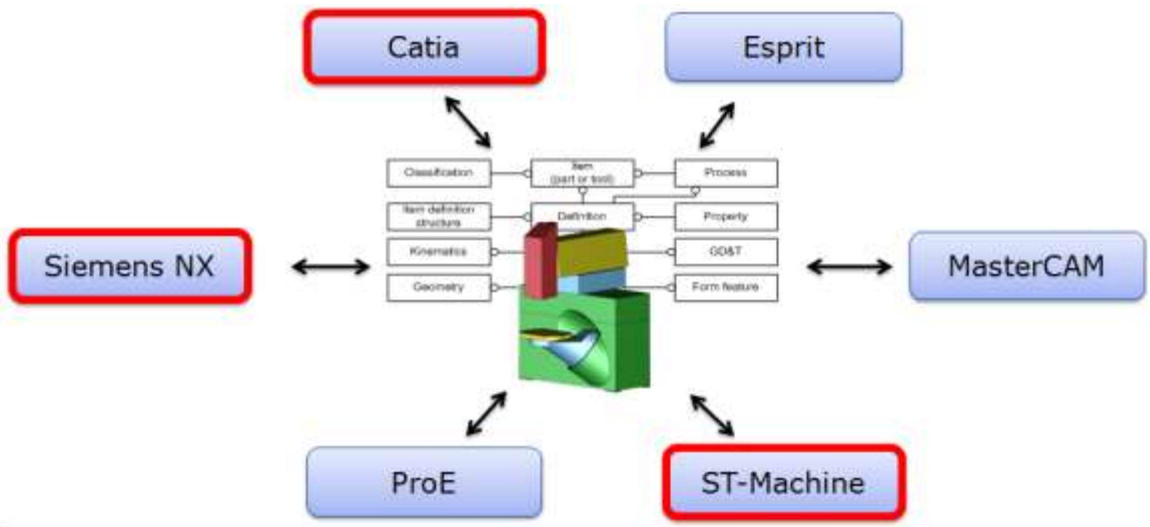

Figure 4: Machine tool model exchange via STEP

the tool during load was measured using laser interferometer. Then, with a resolution of 10 mm, every point (XYZ) within the work envelope was measured. The result of this measurement was then used by NIST who used in-house developed software which calculated the error contribution of each axis to the total error for predicting the positional accuracy of the tool movements. To emulate cutting load a loaded double ball bar (LDBB) measurement device was used. With cutting cross-section based force calculation software, developed by Boeing, information in the STEP-NC machining data was used to predict the deflection of the cutting tool under load. Based on the measurement result from the laser interferometer and the LDBB, the actual position of the tool during cutting load could be estimated. When the machined Crown wheel was measured, the shape of the observed deflection correlated with the prediction, but the magnitude of the observed deflection was smaller than predicted.

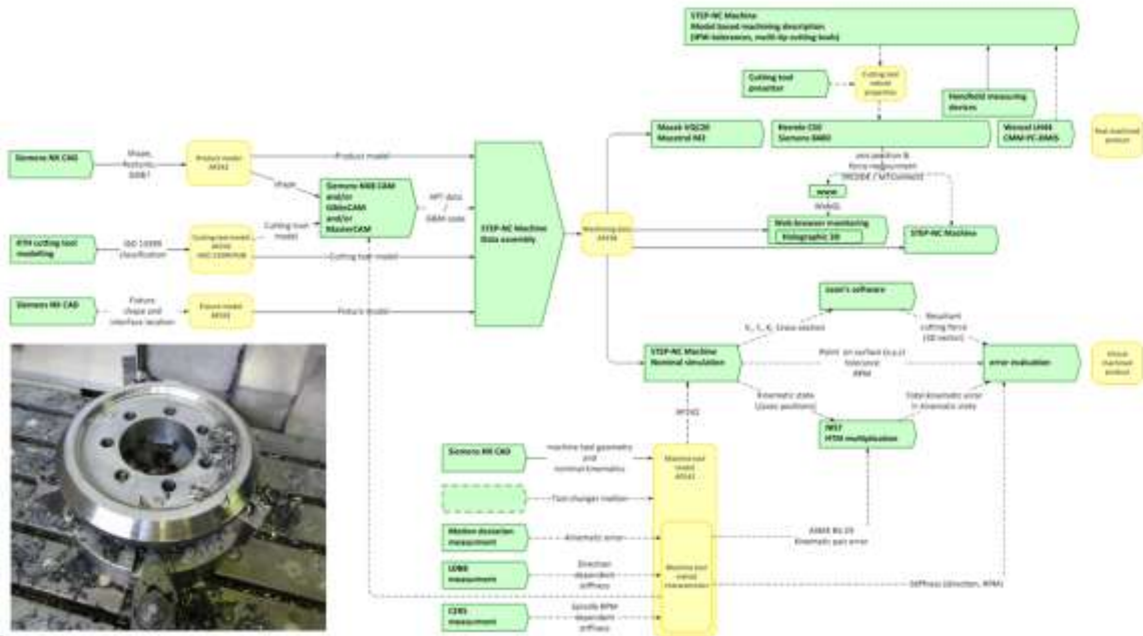

Figure 5: Model based machine tool accuracy prediction

By Swerea – IVF and KTH another developed application of feature based operation planning was demonstrated where Finite Element Analysis was used to simulate the effects of clamping deformation and residual stress on a workpiece during machining. The demonstrated scenario (*Figure 6*) was machining of a forged Scania crown wheel blank which was assumed to have both shape distortions and residual stress after forging. When clamped, the pressure from the chuck jaws causes elastic deformation of the

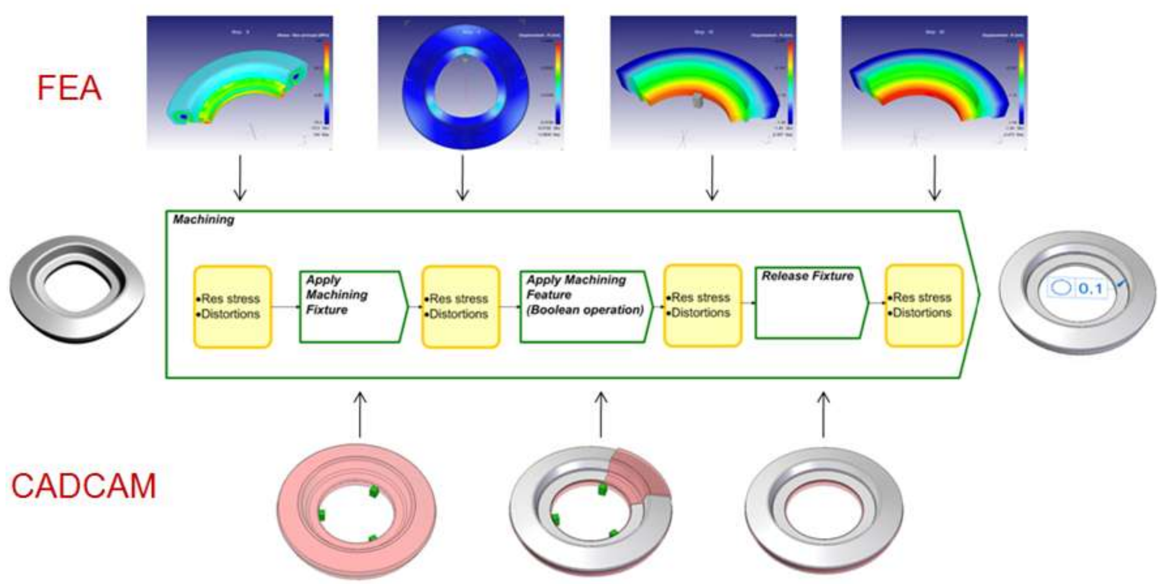

Figure 6: Simulation of manufacturing sequences for verification of product properties

workpiece. Then, during machining, residual stress in the workpiece becomes released as a consequence of the material removal. Finally the workpiece is unclamped and spring back. The question the demonstrated simulation aims to answer is what final shape the workpiece will have after machining – i.e. will the workpiece be within tolerance. Besides the examples presented here, other important project results have been published in the scientific papers listed in section *6.2 Publications*, and in the separate technical report of the project.

5.1 Delivery to FFI-goals

The vision with this research project and its expected results was to contribute to the development of efficient and qualitative operation planning for agile manufacturing of today's and tomorrow's environmentally sustainable automotive components and products in Sweden. It can truly be said that the project has worked faithfully towards this vision, as the project, its demonstrators, publications and other results are important contributions to enable efficient operation planning using digital tools for planning, analysis, validation and verification. Virtual manufacturing requires qualitative information models capable of representing the properties desired to study. It has been a strategic approach within the project to utilize and advocate for usage of system neutral information standards prior proprietary formats. Information transparency enables users to reuse and share stored models of products, processes and resources, thus decreasing non-value adding rework and securing data longevity. Indirectly, the project results will contribute to minimize environmental impact as efficient operation planning enables more effort to be focused on designing the production using sustainable technology and, above all, to be able to manufacture products to higher tolerances in materials more difficult to machine. Also, proper usage of virtual manufacturing can reduce the environmental impact as being able to do right from the beginning will lead to minimized scrap parts from our manufacturing plants, hence the need for remanufacture, transport, and melt down / cast new products will decrease, which all together will reduce the energy consumption on all levels. Regarding knowledge sharing and dissemination of results and experiences, this type of research project establishes and increases the collaboration between academy and companies. From academy point of view this type of collaboration is very beneficial as the involvement of company experts supports the researchers to stretch the limit of established knowledge in the research field. The demonstrators of WP 8 are all good examples where industry contributions have helped researchers to formulate new questions and put available CAM applications to a test. Even though the result of these tests hasn´t fulfilled all the goals formulated with the different demonstrators, they have anyway contributed to highlight shortcomings of today´s software for both industry and academy. They have also contributed to give software suppliers a better understanding of industry needs. A further advantage has been the composition of industry partners who have been able to contribute experience and problems from their manufacturing areas which have been mutually beneficial to all of them. As information and knowledge has been shared between the participating companies they have increased their knowledge and become more competitive. From academy and education point of view the collaboration has contributed to develop state-of-art courses in manufacturing engineering, which in good ways prepare students for the reality that they will face in industry, from all points of view, a fruitful collaboration that has strengthened industry, academy and researchers.

6. Dissemination and publications

6.1 Knowledge and results dissemination

When discussing knowledge and result dissemination, industry and academy have slightly different goals with their participation in projects like this one. Industry is quite naturally interested in results that can improve their business, while academy and the researchers are interested to get scientific accreditation by publishing project results in an approved way. However, even though research certainly can develop interesting computer applications for demonstration purposes, it´s not the research´s role to develop full scale groundbreaking applications that can be used by industry. The research´s role is to study industry and based on their observations, apply, improve or develop appropriate technology that fulfills industry need. But implementation of research results should be the system suppliers' responsibility, and industry´s role here is to put up very clear and precise requirements of desired software functionality. As mentioned in section 4 – Project realization, it has been a strategic approach in this project to utilize system neutral information standards to a large extent and avoid proprietary formats, a strategy that enables research to demonstrate possibilities with model-driven operation planning and advantages of using standards. An additional advantage by this approach is the opportunities it brings for research to participate internationally in development of international standards, e.g. within ISO/TC 184/SC 4 where for instance the demonstration of model based machine tool accuracy prediction held at KTH XPRES lab during the ISO meeting in Stockholm, June 2012, was a very good opportunity to disseminate important project results. Furthermore, as demonstrations like this one are based on industry needs, it´s easy to communicate the possibilities with a model-driven approach based on system neutral information standards to industry. In that way, industry will get important knowledge that will be useful when they formulate their requirements for their software suppliers. But perhaps even more important from a dissemination point of view, is the fact that the software suppliers have a much deeper and active participation internationally than nationally, at least in Sweden. Demonstrations such as the ones developed in this project, does not only communicate the possible benefits of model-driven operation planning to industry, they also serve to prove that it´s possible to implement the demonstrated functionality using international standards to software suppliers. From a knowledge and dissemination point of view, the project´s different demonstrations are important contributions that indicates a possible direction for software development, which is good for both industry and software suppliers. Finally, education is an excellent way in which the project results have been disseminated. Through lectures and demonstrations engineering students not only learn about industry need, they also get the opportunity to see what technology is available to fulfill industry needs.

6.2 Publications

During the project period, a number of publications have been submitted and approved. The main part of them is the result of different demonstrations developed within the project.

- Model Based Machining Descriptions (Hedlind M, Lundgren M, Lundholm T, Kjellberg T, 2010)
- Manufacturing resource modelling for model driven operation planning (Hedlind M, Lundgren M, Archenti A, Kjellberg T, Nicolescu C M, 2010)
- Embedding a Process Plan in Function Blocks for Adaptive Machining (Wang L, Holm M, Adamson G, 2010)
- Development of a Model-driven Approach for Process Planning (M.Sc. thesis, Huang Q, 2011)
- Kinematic structure representation of products and manufacturing resources (Hedlind M, Klein L, Li Y, Kjellberg T, 2011)
- Implementation of kinematic mechanism data exchange based on STEP (Li Y, Hedlind M, Kjellberg T, 2011)
- An Adaptive Approach to Planning and Monitoring of job-shop machining operations (Wang L, Givehchi, 2011)
- Using Existing Standards as a Foundation for Information Related to Factory Layout Design
(Chen D, Hedlind M, von Euler-Chelpin A, Kjellberg T, 2011) In collaboration with FFI Digital Factory Building Blocks (DFBB)
- CAPP - A critical review of recent developments and future trends (Xu X, Wang L, Newman S T, 2011)
- Cutting tool data representation and implementation based on STEP AP242 (Li Y, Hedlind M, Kjellberg T, Sivard G, 2012)
- Kinematic error modeling based on STEP AP242 (Li Y, Hedlind M, Kjellberg T, 2012) In collaboration with FFI – DFBB
- A Review of Function Blocks for Process Planning and Control of Manufacturing Equipment (Wang L, Adamson G, Holm M, Moore P, 2012)
- Enabling the crowd sourcing of very large product models (submitted to IFIP PROLAMAT conf.) (Hardwick M, Loffredo D, Fritz J, Hedlind M, 2013)
- Model Driven Process Planning for Machining – Theory, application and improved information standards for efficient product realization (Ph.D. thesis, Hedlind M, 2013)

6.3 Education

The close collaboration with industry in this project, has given the researchers a good opportunity to observe how each company manufacture their products, what type of challenges they face in their manufacturing, what type of need they have, what type of computers tool they need etc. Also, the project has been a very good platform to establish networks between academy and industry, and between researchers and industry experts, altogether, a very beneficial situation for the academy and the manufacturing engineering education. The project has contributed with lot of input to the two courses MG2036 – Computer Aided Manufacturing and MG2130 – Modeling and simulation of industrial processes given at KTH. These two, as their name indicates, are courses in the area of virtual manufacturing, but as virtual manufacturing is just an approach in manufacturing engineering to analyze, validate and verify different alternatives, students still need to get in contact with real manufacturing to really understand it. And here the network between industry and academy is a very valuable asset as industry experts can be invited as guest lecturers to whom students can listen, taking part of their expertise and experiences.

6.4 Other dissemination of project results

Besides dissemination of project results through scientific publications and in engineering education, the project (and FFI- Sustainable Production Technology) and its results have been presented in numerous other situations, such as:

- ISO TC184 SC4 WG3 T1 & T24 (regular meetings)
- ISO TC184 SC4 meeting, Stockholm, June 2012
- SVMF (Association of Swedish Machine Tool Manufacturers)
- FVM – (Association of tool and machine tool manufacturers)
- TK279 and TK280 (regular meetings)
- KT-kluster Conference 2011, 2012
- DMMS – MCR members conference 2010, 2011, 2012
- CIRP The International Academy for Production Engineering (regular meetings)

7. Conclusions and future research

The results from this project are in a long term perspective important contributions to increase productivity and quality in operation planning and in the manufacturing process. The mutual cooperation between research and industry in the project has contributed to maintaining and to some extent increasing the since many years good relations between research and industry in Sweden. Through different demonstrations, the project has not only communicated possible benefits of model-driven operation planning to industry, it has also proved that it is possible to implement the demonstrated functionality using system neutral international standards for information modeling. Most of the demonstrations have been internationally recognized as important contributions within the field of virtual manufacturing and contributes to make Swedish research within virtual manufacturing internationally well known and respected. To keep this position it is important to continue with research about model-driven operation planning. One suitable area in which the work could be continued is the Production Part Approval Process – or PPAP for short. PPAP is used in the automotive supply chain to establish confidence in component suppliers and their production processes. The purpose of PPAP is to confirm that suppliers have properly understood all the design and specification requirements for the components they supply, and that the supplier's process has the capability to consistently deliver products that comply with those requirements. Today´s

PPAP is a labor intensive process as there are lot of documents that have to be written. The manufacturer has, for every geometrical dimension and tolerance of a product, to document how they are manufactured and what possible sources of deviations there are. A work intensive task as automotive components such as an engine head for instance, may contains several thousand different geometrical dimensions and tolerances, each one having several possible sources of deviation which must be under control. Using a model-driven approach instead of today´s document based PPAP would allow a possibility to link a feature, its dimensions and tolerances to a certain and capable manufacturing process (tool, machine tool, fixture) with a valid measurement method, i.e. a method capable of evaluating a certain dimension, performed by an approved operator using an approved measurement device. A model-driven approach would make current PPAP for machining more efficient and increase productivity in as well process planning as in production.

8. Participating parties and contact person

Contact person for the project: Magnus Lundgren, KTH – Production engineering