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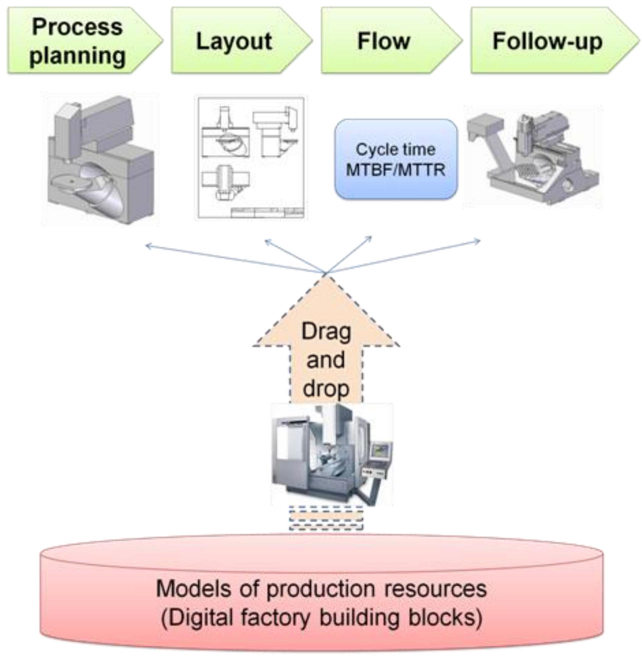
Digital factory building blocks



Reusable models in production

Project within FFI Sustainable production technology

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May 30th 2012

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Executive summary

In the lifecycle of large scale manufacturing systems, including design, operations and maintenance, several digital models and Virtual Manufacturing (VM) tools are utilized for process planning, layout design, robot simulation, etc. A main obstacle, which prevents using this technology in a larger scale, is the cost and time needed for building realistic and accurate models of planned and installed manufacturing systems; Digital factories.

The goal of the project Digital factory building blocks (DFBB) was to define how to build a system neutral repository of manufacturing resource information usable for building the Digital factory. In system neutral resource models, or building blocks, information from many different IT-sources would be harmonized and reused for various applications. The resource models should also be kept updated and accurate throughout the whole lifecycle of manufacturing, thus supporting a fast development and change of factories.

DFBB was a 3 year, 15 MSEK, research collaboration between KTH, Chalmers and Swerea IVF with a four-fold approach: 1) define the main principle for representing resource information, integrating information from different sources; 2) define how to update these models with operational data; and 3) demonstrate reusable models in cases selected by the industrial partners Scania and Volvo. 4) Disseminate the ideas and results to small and medium-sized companies and develop methods to support their use of digital factory solutions.

The main focus and contribution of the project was that of showing how existing standards can be used for representing and communication other than geometry data. This is a basis for creating interoperable models of properties such as kinematics, operational statistics, technical and administrative attributes.

In short, the project has demonstrated reuse and updating of resource models in two use cases: one at Volvo concerning geometry and kinematics; and one at Scania concerning operational data, updating the model and using it in flow simulation. The basis for the demonstrations is a standardized information model based on the international standards CMSD (NIST) and STEP (ISO). We showed how to achieve interoperability between the CAD systems Catia V5 and Siemens NX 7.5, and also between the GDM tool (developed by Chalmers) and ExtendSim, a discrete event simulation tool developed by Imagine That Inc.

To summarize, the project has met the goals and demonstrated how to model and update models in several ways:

1) Through the definition of how to describe resource information in system neutral formats - an information model following established international standards.

The standardized representation of kinematics in AP214 and part 105 of ISO 10303 STEP was developed further, contributing to the evolvement of AP214 as well as to the new standard AP242. Some of the information models have contributed to the development of international standards (Chalmers-CMSD; KTH-STEP), other parts represent a hypothesis that operational data can be represented in the STEP-standard.
2) Through the development of a method for export/importing data from vendor systems, based on the information model.
3) Through the implementation of software for demonstrating the communication of resource data between various systems, verifying the applicability of the approach.
4) Development of a software for creating stochastic information based on measured operational data - the GDM-tool.
5) Demonstrating the system neutral resource models in two cases identified by the industrial partners. Further showing how information from each of the cases could be harmonized into one model, enabling reuse.

Background

Virtual Manufacturing (VM) tools have been identified as important enabling technologies of agile manufacturing and its related activities. In the lifecycle of large scale manufacturing systems, including design, operations and maintenance, several VM tools are utilized for process planning, layout design, robot simulation, throughput analysis, etc. A main obstacle, which prevents the usage of this technology in a larger scale, is the cost and time needed for building realistic and accurate models of planned and installed production systems.
The problem is that information is incomplete and inconsistent: it resides in various systems and applications, in different formats and with various levels of detail and viewpoints. This is especially troublesome when companies who collaborate (OEM, suppliers of fixtures, tools, machines etc.) use software from different vendors using different data structures. To facilitate the communication and sharing of information between different applications, it is necessary to use common formats. There are many existing neutral formats, but they are developed for different and more or less specific purposes, and are not harmonized with other aspects of the manufacturing domain. For a deeper description of state of the art we refer to the descriptions of the work packages below.
The other powerful motivator for this project was that the highly increased pressure on lessening environmental effects from factories calls for assessment tools in order to calculate these effects. As the product and the process data historically lack information on environmental effects, we introduced such information carriers into the virtual manufacturing and manufacturing data management agenda. With environmental parameters as a part of product/process/resource models, it will be possible to frontload the development work into the virtual world and at the same time incorporating environmental measures as a part of the available information in the decision process.

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Objective

The long term goal was to create a system neutral repository of production information - a library of digital resource models - which harmonizes information from many different IT-sources and can be used in various applications. These resource models, or digital building blocks, should be kept updated and accurate throughout the whole lifecycle of production, thus supporting a fast development and change of factories.
The objective of the project was to contribute to this goal by selecting and combining data formats which can represent a selection of production resources and enable interoperability of information. One of the key means when integrating information with different scope, levels of abstraction, or detail, is the conceptualization of the domain – defining concepts and their relationships in such a way that models from various viewpoints can be integrated into a whole.
But companies today often already have a set of established models, tools, methodologies and software structures which are useful even if they are based on incomplete and not coordinated information. The time and effort to tear up these existing structures would result in a huge loss of income during too long a time frame. Thus, an applied approach was suggested in this project: to start from each company's existing situation, and define a workable method to enable easy changeovers towards a more structured information approach. This approach will also be favorable for suppliers to follow the path.

Project realization

The main project goal was to demonstrate a series of steps towards the long term goal of neutral resource libraries. The demonstrators required deliverables from the project work packages and thus served to focus and coordinate the project activities.
The project was divided into 5 work packages:
WP1: *Industrial targets and parameters* – maps needs for digital analysis and requirements, including the possible environmental analyses, to guide the case studies and demonstrators
WP2: *Digital building block library* – specifies how to model the digital building blocks
WP3: *Integration of operational data* – defines how to include historical data in digital factory and building blocks
WP4: *Digital factory work method for suppliers industry* – considers the context of suppliers by establishing a two-way communication
WP5: *Demonstrator* – plans and implements a set of demonstrators, requests results from the other WPs
The work packages had the following roles and participants:

Part	**Area**	**People**
Swerea IVF	WP1 - Research WP4 - Research	Per Gullander, Magnus Widfeldt, Roger Lundin

FKG	WP4 - Participation in workshops	Faurecia, VBG group, Haldex Brake
Chalmers	WP3 - Research and development	Björn Johansson, Anders Skoogh
KTH	WP2 - Research and development	Mikael Hedlind, Yujiang Li, Navid ShariatZadeh, Gunilla Sivard, Astrid von Euler-Chelpin, Torsten Kjellberg
KTH	WP5 - Implementation and verification	Mikael Hedlind, Yujiang Li, Navid ShariatZadeh, Linus Persson, Annica Ivert, Christer Wickman
Volvo Technology	WP5 - Specification and implementation	Thomas Lezama, Andreas Bergstrand
Scania	WP5 - Specification	Lars Hanson
KTH	Project lead	Gunilla Sivard

Results and deliverables

Delivery to FFI-goals in general

This project enables more extensive utilization of virtual tools thanks to increased interoperability of the manufacturing related data. The *interoperability* in-between different software architectures and also in-between real world systems and virtual tools is considered a key enabler for, firstly, productive manufacturing engineering. Secondly, enable a *more seamless integration in-between the virtual world and the shop floor*, i.e. to utilize the virtual work in the real world processes. Thirdly, aim to *provide data in useable format* in order to enable utilization of the virtual technologies for optimization of the manufacturing processes *environmental impact* before production starts. In more detail this project provided means to enable for example:

- Faster ramp up to a production rate corresponding to current market demand at product changes both in existing and new manufacturing systems.
- More reliable support for continuous improvement work to reach high production efficiency and productivity.
- Manufacturing processes and systems with known impact on environment and climate.
- Early indication on manufacturing resources available; decreased response time for analyses of the impact of changes from product development, changes in volume or product mix, and other constraints
- Increased level of detail in conceptual analyses of production
- Various forms of raw data, availability and capability measures per resource, and environmental impact measures per resource

Specific results

Definition of information models for manufacturing equipment, development of ISO10303, STEP

The STEP standard is general and structured to enable interoperability and integration of information from various perspectives and types of applications. One important principle to achieve this is to separate data of different kind, and interrelate them with declarative relations, thus avoiding the structuring of data in a way that is only suited for one specific area of application. The standard has the capability of representing a broad range of information, but is currently only industrially used for communicating geometry in a system neutral format.

In the project we have provided a proof-of-concept, through the first valid data model of the STEP kinematics and a series of implemented demonstrators, that it is possible to represent and implement resource information in a standardized format that enables interoperability: ISO 10303 AP214 and AP242. This proof-of-concept and the evolvement of the standard concerning kinematics, are important contributions recognized by the ISO committee SC4. The standard can be used for implementation by vendors of IT-systems, and a kinematics export following STEP has been developed for IDA STEP by German LKSoft and ST Machine by American STEP Tools and is under development by Dassault Systèmes.

Further, we have verified how to represent stochastic operational information in STEP so that it can be integrated with the resource model and used for communication between follow up and flow simulation applications.

Specification of how to create, manage, combine and use resource models as building blocks for selected applications.

A STEP Toolbox was developed within the project to provide a maintainable, reusable, and extensible programming interface to simplify STEP implementation for CAD/CAM developers. The modularization of the toolbox is illustrated in Figure 1. Via ISO 10303-22 SDAI (Standard Data Access Interface); STEP p21 files and other supported file types can be manipulated by several programming languages. The STEP Toolbox offers a modularised Java programming interface to process different types of product information, e.g. geometry, kinematics, classification, and GD&T (Geometry, Dimensions and Tolerances). To enable a high level of maintainability, multiple functionalities are separated into independent modules for different industrial usage. The STEP model manager, data model -, and mathematics modules provide the general functions to support the operations of modules. Thus, with little STEP knowledge, developers can produce their own applications or plugins for CAD/CAM software based on the standard. The third level of the illustration introduces available applications based on the STEP toolbox.

KIBOS (KTH Implementation Based On STEP) for NX/ST-Machine is the first application developed to validate this principle. With little STEP development experience, developers at Volvo implemented a kinematic translation plugin for CATIA based on STEP toolbox.
Further, the CMSD to STEP translator uses the same principle using the process data and statistics modules for converting CMSD data to STEP representation and the STEP to Extend application translates flow data to the discrete event simulation tool Extend.

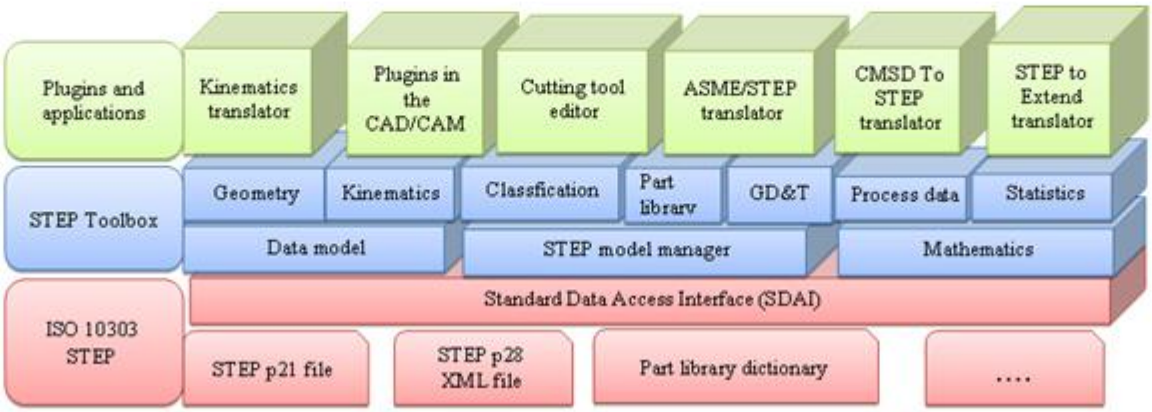

Figure 1 Toolbox architecture

Deliverables concerning Automated Data Management

The DFBB project has developed and evaluated a concept for automated handling of operational data (Figure 2). The concept is also implemented in a software demonstrator called the GDM-Tool (Generic Data Management). These results are further developments of research originally initiated during the MERA research program in a project called Conceptual Factory Development. Three independent case studies prove that the time-consumption for management of operational data can be reduced by approximately 75% relative a traditional industrial approach.

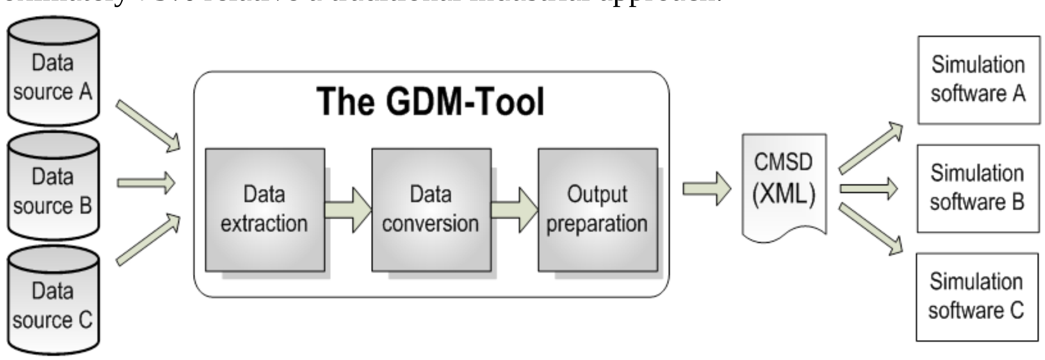

Figure 2 Developed concept for automated management of operational data.

The concept includes automated extraction of raw data from several differently structured data sources, as long as they are computerized and possible to represent as related tables. These prerequisites are applicable to a vast majority of data sources in Swedish industries. The GDM-Tool then provides a set of default data operations for transformation of data to information for the digital building blocks and the analysis tools using the resource models. Among other capabilities, the tool can automatically condense data points to statistical distributions; see Figure 2. Finally, the results are automatically exported to a neutral format, here exemplified by the Core Manufacturing Simulation Data (CMSD) (SISO-STD-010-2011).

Representation of Sustainability Parameters

To enable application of the digital building blocks in analyses aimed at increasing the ecological sustainability in production systems, the project has investigated how sustainability data parameters should be represented. The starting-point was to study the demands of data representations in discrete event simulation (simulation of production flows) due to its high requirements on level of detail and the possibility to describe dynamic behaviors. In a study at Scania, the electrical power levels of five tooling machines performing milling operations were sampled in busy, down, idle, and stand-by modes (Figure 3). The varieties between these different machine states were limited resulting in the electrical power data can be represented using deterministic values in simulation models and in our digital building blocks. This is one important parameter in sustainability simulations but there is a future need for performing similar studies on other related parameters. An interesting additional result showed that approximately 33% of the energy-consumption can be derived to non-value-added time, which supports the need for detailed analysis of production flows to increase sustainability in Swedish industry.

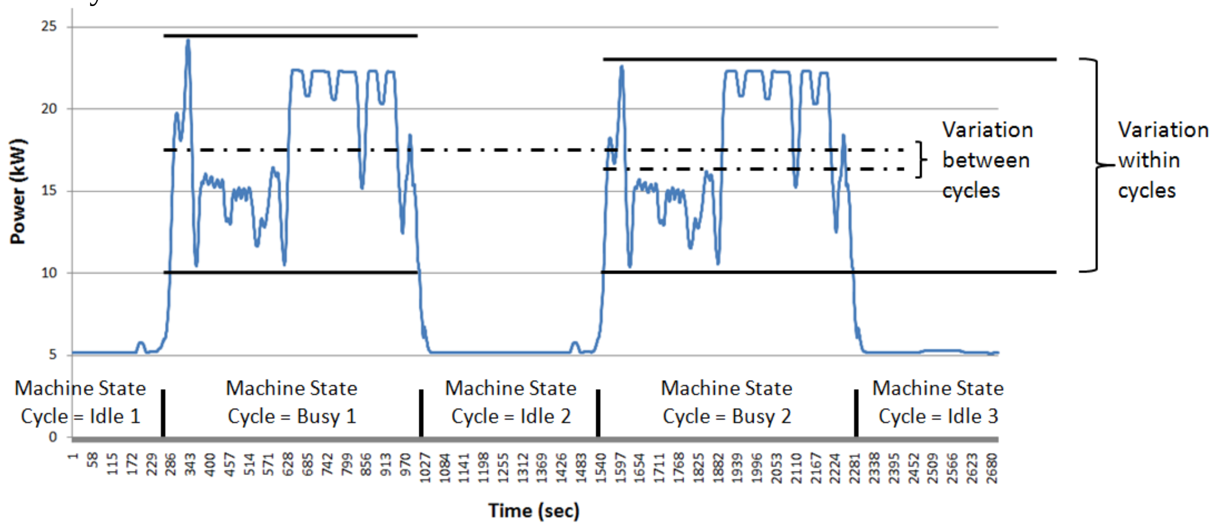

Figure 3 Variation of electrical power levels in different machine states.

Development of CMSD

Apart from contributions to the STEP standard, the standard CMSD has been further extended in cooperation between National Institute of Standards and Technology (NIST) (USA) and Chalmers. The cooperation has demonstrated how to apply CMSD for version handling of data points in digital building blocks. The same standard has also been extended to include electrical power data, which was not done before the DFBB project.

Forecasting the Behavior of new Production Equipment

The above mentioned version handling for digital building blocks enables a structured work procedure for forecasting the behavior of new building blocks by closely studying historical data for similar manufacturing processes. The work procedure is based on that a group of process experts examine data for the specific production resource in earlier phases of its life-cycle and/or data for similar processes with a more extensive set of available information. In such way, the digital building blocks can facilitate combination of data and information, for example form the machine vendors, behavior of the same type of production resource at other companies, prototype production, and full operations. By combining this type of information, parameters like power levels, Mean Time Between Failures (MTBF) and Mean Time To Repair (MTTR) be predicted more precisely than before the DFBB project.

Demonstrators

For the demonstrator case at Volvo, a method for STEP data exchange of kinematics and 3D shape between Catia V5 and NX 7.5 was developed.

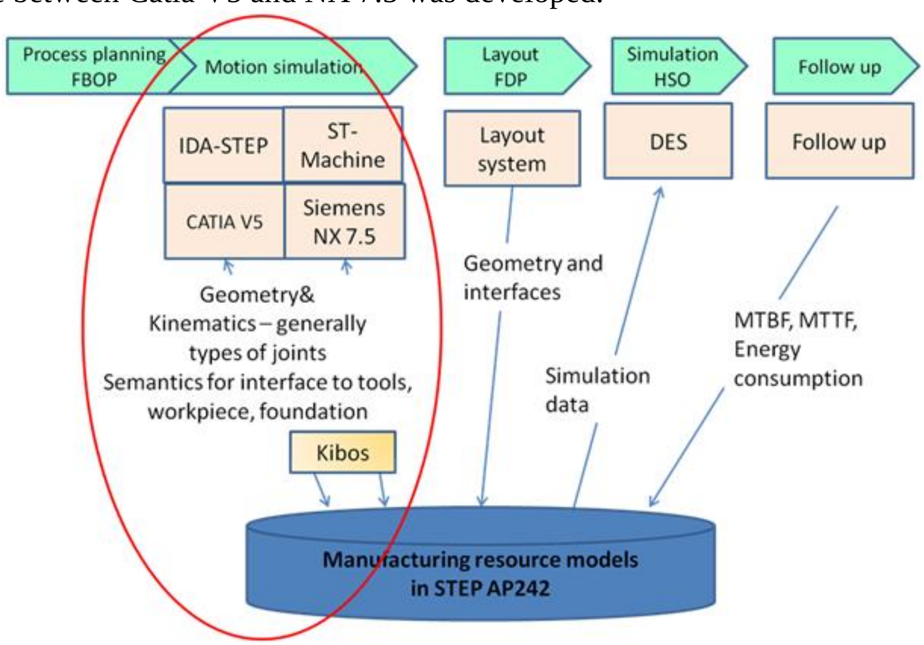

Figure 4 Focus of Volvo demonstrator.

To accurately perform robotic simulations and related analysis, resource models need to include geometry, kinematics and other attributes. Resources of interest other than the robot/machine tool itself include fixtures, grippers, weld guns and weld machines.

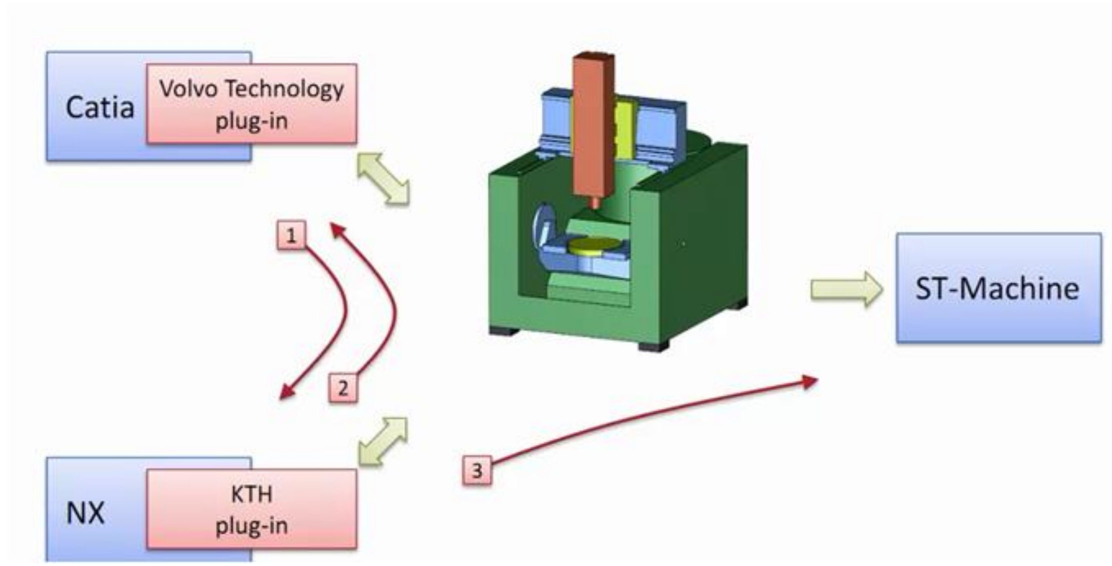

Figure 5 Communication of kinematics between Catia and NX.

The latest standard data format, STEP AP242, was utilized to support communication of kinematic mechanism between CAD systems. As mentioned before, the STEP Toolbox is employed as API (Application Programming Interface) to enable STEP implementation by common developers. Using the same API, the plugins for STEP export/import based on CATIA and NX were developed.

Demonstration of Scania use case of a resource handling system which holds relevant resource data and communicates data to selected information systems.

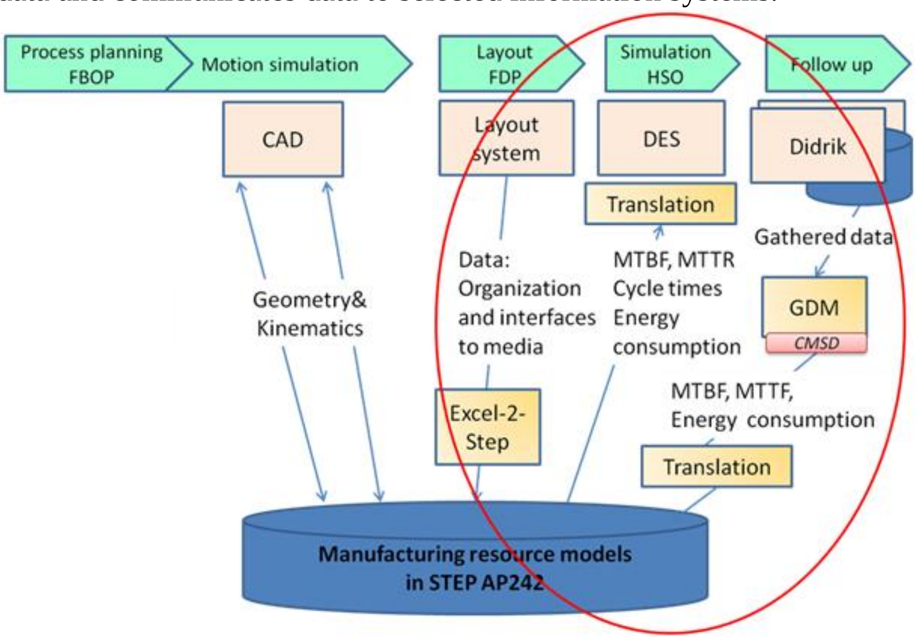

Figure 6 Focus of Scania demonstrator.

The case study at Scania includes machines performing milling operations and they are arranged as a serial production line including parallel machines within operation steps:

The input parameters automatically supplied to the DES model are MTBF and MTTR. The time consumption is evaluated using the comparison described in WP3.

The same data for MTBF and MTTR were used and the transformation to information for the building blocks is identical to case 1 of WP3. Therefore, no additional comparison of the time-consumption is performed. The difference between this demonstration and case 1 in WP3 is that this final demonstration included the parameters electrical power levels and cycle times for the machines. Both these parameters were collected within the DFBB project and supplied to the GDM-Tool via person-based spreadsheet solutions. The proposed concept proved to be capable of extracting the necessary data from three different sources, automatically analyze and process the data, and supply them to the building blocks using neutral formats. The data were thereafter used in simulation models and visualization applications.

Data from GDM-tool was translated to STEP in order to enable consolidation with other types of resource information. The integrated model was then translated into ExtendSIM and also visualized in a prototype STEP viewer developed within the project.

Workshops, network and holistic model to stimulate digital factory solutions

Many of the suppliers of Scania and Volvo, and the automotive industry in general, have not invested in digital solutions as much or come as far as their customers, even though they have similar needs and requirements. The project has conducted workshops, company case studies, and formed of a group of stakeholders interested in digital factory solutions.

Altogether people from 19 companies attended two workshops (13 from FKG) where ideas and thoughts about of the "digital factory" were presented and discussed. The group of participants will be maintained and formed as a network of participants from the automotive components group, FKG. The purpose is to provide a channel for the dissemination of new ideas and results, and getting the opportunity to capture business problem scenario, perspectives, assumptions, and bring it back into research and development projects.

The results of the study visits and workshops provided input to forming a conceptual model and method intended to support, in a structured manner, companies in assessing, reflecting, and compiling a picture of their level of use of different kinds of simulation modeling and analysis methods, on an overall level. The model has two "dimensions", which can be combined to form any simulation use (Figure XX). First, the purpose / goal of the simulation analysis: Communication & Education, Design, Capability/Delivery , Losses/efficiency, Other effects (ergonomics, work environment, environmental effects, social sustainability), and Programming. Secondly, the object/system/item being analyzed: Product/components, Processes, Tools/fixtures, Equipment/stations/Work place, Production line/flow, Factory/Plant, and Logistics. It is the intention and the believe that, based on the holistic model, any company could benefit from analyzing its present way of working and potentials of new solutions.

Objective of simulation (purpose, questions)			Object that is simulated						
			Product and Component	Production Process	Tools and Fixtures	Equipment & Station	Production line / flow	Overall Site/ Plant	Intra plant logistics
	COMMUNICATION EDUCATION:,	1	3	0	3	3	3	1	2
	DESIGN : GEOMETRY, MATERIAL, POSITION.	2	3	0	2	2	2	2	2
	ANALYSING DYNAMIC & STATIC PROPERTIES & CAPABILITY:	3	3	1	3	3	3	2	3
	ANALYSING INEFFICIENCY/ LOSSES:	3	3	2	1	2	3	2	2
	ANALYSING ERGONOMICS, SOCIAL, ENVIRONMENTAL	3	2	1	0	1	0	1	1
	DECIDING & PROGRAMMING OBJECT's OPERATION:	4	1	2	2	2	1	0	1
	SUPPORTING MANAGEMENT AND OPERATION OF OBJECT	5	1	2	2	2	0	0	1

Figure 7 Holistic assessment of usage of production simulation for various objectives on different objects.

Dissemination and publications

Knowledge and results dissemination

The results of the DFBB project have been disseminated in workshops with the FKG partners as well as in conferences – both in the FFI "Klusterkonferens", and in international research conferences. Still, we believe that one of the strongest impacts is by contributing to the international standardization work in ISO and NIST. A specific driver of change is the implementation of applications based on the standards, proving their utility both to industry and IT vendors, thus pushing the development in the direction that the manufacturing industry needs.

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Conclusions and future research

An experience from the project is that one of the strongest impacts and drivers of change is to implement APIs based on the standards, proving their utility both to industry and IT vendors, thus pushing the development of vendor systems in the direction that the manufacturing industry needs.
Future research includes a more general consolidation mechanism as well as extending the information that can be managed, for example the inclusion of dimensions and

tolerances in the models. The DFBB project has been collaborating with the FFI FBOP project to achieve this, and the FBOP project will continue the work.

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- Haldex Brake Products
- Faurecia

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