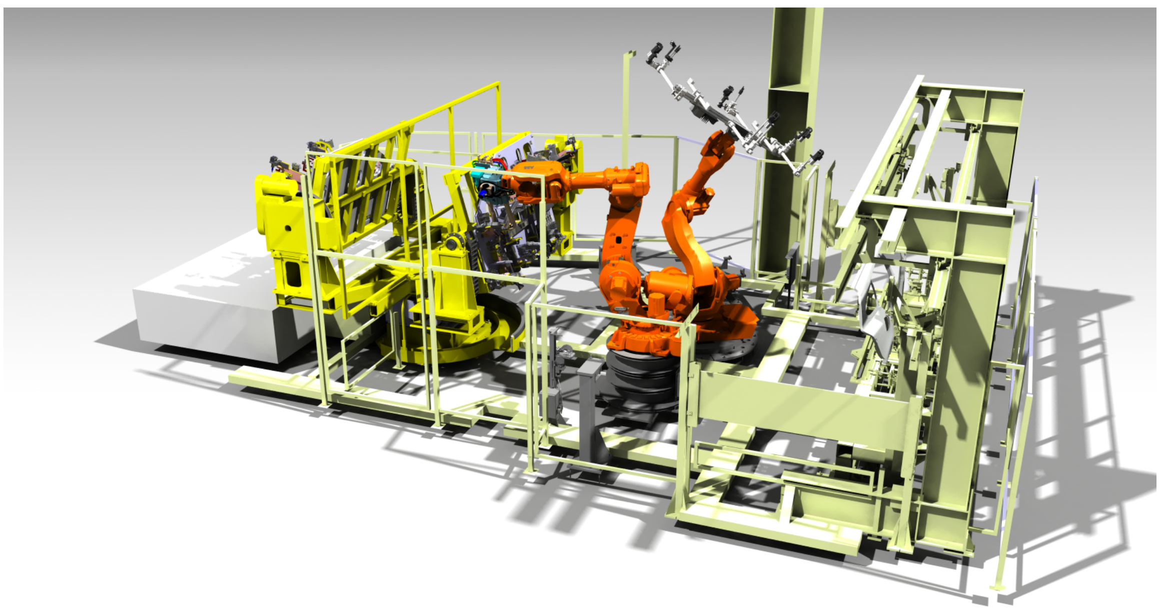
Virtual commissioning of manufacturing stations including PLC logics



Project within Hållbar produktionsteknik

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FFI

Content

FFI in short

FFI is a partnership between the Swedish government and automotive industry for joint funding of research, innovation and development concentrating on Climate & Environment and Safety. FFI has R&D activities worth approx. €100 million per year, of which half is governmental funding. The background to the investment is that development within road transportation and Swedish automotive industry has big impact for growth. FFI will contribute to the following main goals: Reducing the environmental impact of transport, reducing the number killed and injured in traffic and Strengthening international competitiveness. Currently there are five collaboration programs: **Vehicle Development, Transport Efficiency, Vehicle and Traffic Safety, Energy & Environment and Sustainable Production Technology.**

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1. Executive summary

The purpose of this project was to create an energy-, time- and cost efficient preparation procedure for production systems producing complex products. The project would also contribute to energy efficient and flexible production systems with a reduced number of discarded parts. Another aim was to be able to handle a growing variety of vehicles in relation to environmental requirements on CO_2 emissions by designing more flexible manufacturing stations. The purpose was also to increase human and machine safety by performing virtual simulation and verification of all involved components within a station. The project was a co-operation between both vehicle manufacturers and suppliers, something that was crucial for effectively reaching the main goals. The project's main point was that information should only be created once. The project would integrate preparation activities and tools in order to increase preparation efficiency. The project results will be integrated in existing activities at the involved companies, as well as in a physical demonstrator that was built at Chalmers. Upcoming master courses in virtual preparation will use this demonstrator.

As the project has covered the whole chain, from early production preparation phases until final commissioning, the tasks have been divided into a number of sub-tasks. In a separate work package the more holistic view that information can be reused and that use of virtual development tools can be accomplished was investigated together with the question of what such a virtual workflow would look like. As can be seen in Figure 1 a large number of developments and investigations have successfully been performed.

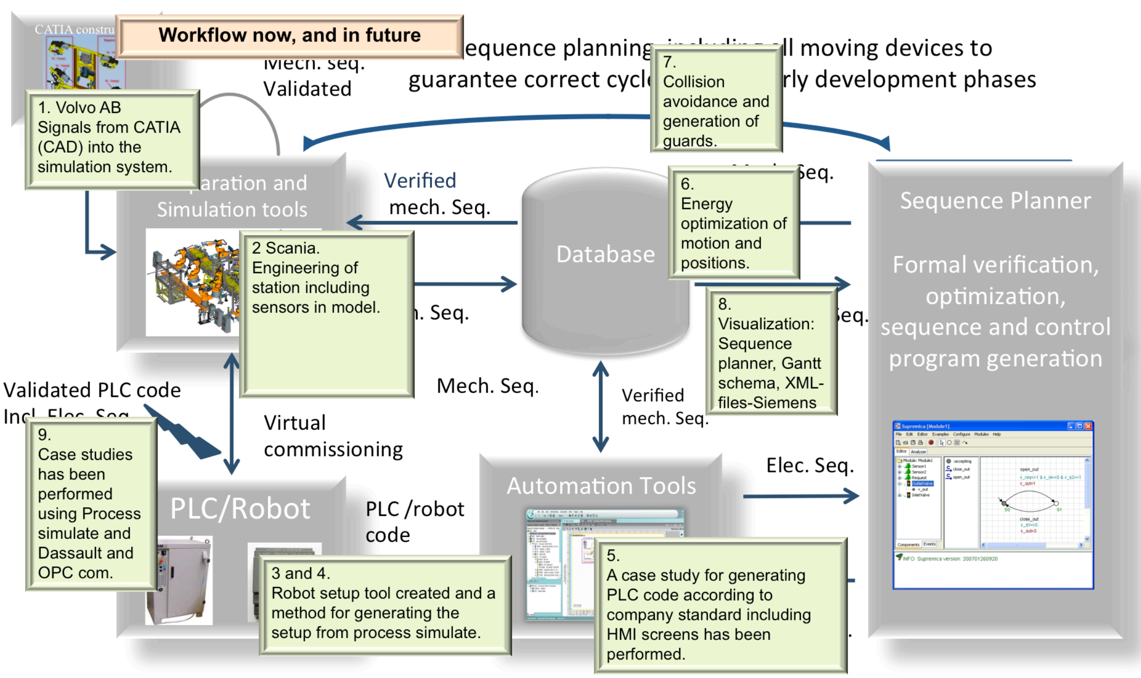

Figure 1 Sub-tasks performed during the project.

The activities of the project are described in Figure 1. The first activity deals with the problem of creating logic behavior information in a CAD tool and being able to use this created information in the simulation tool.

The second activity attempted to fully utilize state of the art virtual development tools to prepare an existing manual station into an automated station. This production preparation had the goal of generating PLC-logic based on already creation of information in CAD and simulation tools.

In the third and forth activity software was developed that enabled automatic generation of complete robot programs. This means that it is possible to reuse configuration data about the robot and its equipment from a simulation tool., and automatically configure the robot programs.

The fifth activity was aiming at automatically generating complete PLC-programs including HMIs based on simulation results and function block libraries. The result showed promising possibilities in automating the programming of production systems. However, changes in what is done in the preparation phase proved necessary,

The sixth activity focused on showing how production systems could be optimized, not only with respect to cycle time, but also when it comes to energy consumption. Results show that when designing a production system, energy consumption should be included as an constraint during early stages of the design since the layout is an important factor in how sustainable the final solution will be.

The seventh activity developed a method for automatically designing efficient production system solutions without collision problems involving all equipment. A case study showed that it was possible to turn a three-station production system with in total 12 robots and a total cycle time of 3 min into a collision free two-station system with in total 18 robots and a total cycle time of 2 min.

A major problem when designing really complex systems as the two-station system with 18 robots is the fact that it is hard to understand the detailed and general behavior. A method that automatically visualizes all the behavior in a user friendly way was therefore developed in activity eight.

In the ninth activity virtual commissioning of the entire control system was performed using existing state of the art software. This clearly showed that this is becoming possible and in fact more and more companies are using this in order to save valuable time in the commissioning stage.

One of the major aims was to investigate how modern workflows should be defined in order to be able to use as much of the state of the art preparation tools and at the same time reuse as much of the information as possible. Another important aim was to be able to draw conclusions about who is going to do what in order to establish a well-defined workflow. The result shows that in order to take all equipment into consideration and take advantage of state of the art optimization techniques it is necessary to change the structure of who is doing what and when already in the early preparation stages.

2. Background

Vehicle manufacturing companies are today forced to handle a rapidly growing variety of vehicles due to the environmental restriction on energy consumption and CO_2 emissions. A requirement is that the introduction of these new innovative and environmentally friendly vehicles must be produced in existing factories. Today´s manufacturing systems therefore have to be both efficient and flexible to manage this complexity. Another important requirement is that the need for energy and material for both preparation and running of today´s productions systems have to be kept to a minimum. This places great demands on manufacturing systems design, development, and testing before implementation. It also places great demands on optimized use of equipment, material and energy when production systems are up and running. This also means that the number of production errors is kept to a minimum. An effect of this is that accurate simulation, verification and optimization must be performed before systems are taken into use. It is important to be able to optimize the stations before they are built. Today reachability tests are performed that minimizes the number of errors in the design and relatively good stations are built. This is of course an advantage. However, it is often the case that the final stations are badly optimized. This can lead to two things. A re-balancing to other stations becomes necessary and as a consequence the simulation model is no longer valid. The stations inactive time is increased; this leads to waste of both resource and energy. Figure 2 shows the current situation where design activities are performed more or less independently and the control implementation is not performed until the actual station is built.

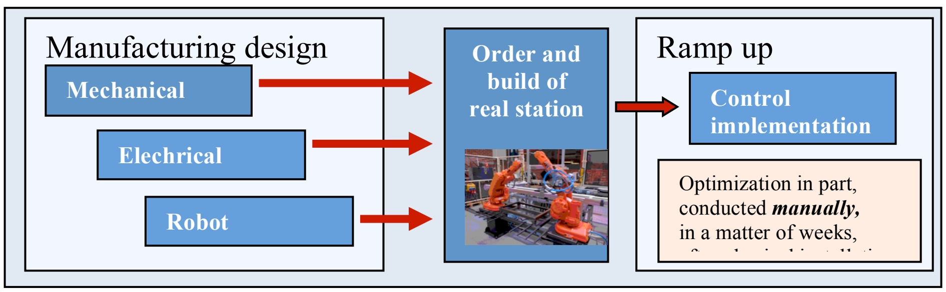

Figure 2 Current situation: Control implementation is performed after equipment is ordered and built.

In early development of manufacturing stations the movements of devices, especially robots, but also conveyors and fixtures, are typically designed and analyzed neglecting the more detailed coordination of the different devices including clamps and sensor feedback. This means that stations often need to be redesigned more or less, when the logic complications are taken into account.

A natural step is then to extend early process design and mechanical simulation with control logics to ensure a correct behavior. With current technique it is hard, however, to include sensors and PLC logics although it is technically possible with software such as Process & Line Simulate and Delmia Automation. New software from Siemens and Dassault Systemes can then interesting enablers.

Figure 3 shows how the project aims at bringing the control implementation into the preparation phase before the actual equipment is ordered and the station is built. It also describes how preparation activities work independently but with a close cooperation using the same information base.

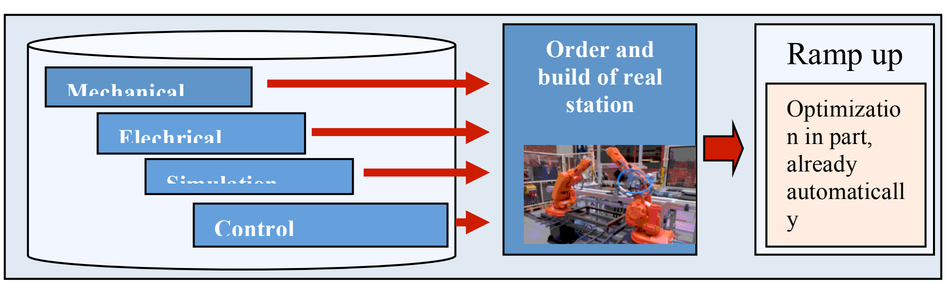

Figure 3 Project Approach: Include control implementation in production preparation and use common framework

This project can be considered a natural continuation of the station logics part of the Wingquist MERA project [1], but now with more focus on simulation and optimization and an extended interface to upstream information and working procedures. Three cells with different character have been implemented in Process Simulate and one cell in Delmia automation. These cells can be used as demo examples in the research project. One robot cell has been built.

3. Objective

The general objective of this project is to define work procedures, see example in Figure 4, in order to enable virtual commissioning of production stations including complete PLC and robot programs. The project focuses on delivering methods for virtual development of both station logic, including all equipment, and robot control programs including tooling equipment. The project will deliver methods and work procedures for producing more accurate cycle time analysis in early production preparation phases.

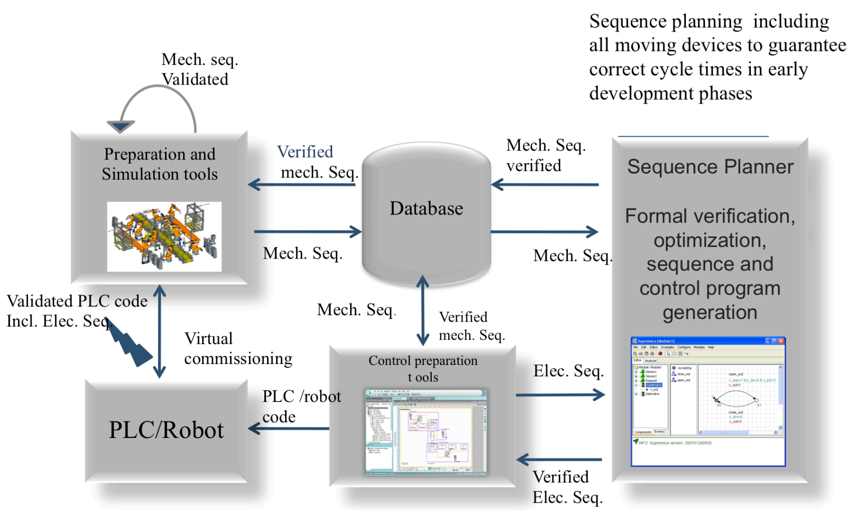

Figure 4 Proposed workflow for preparation of control of a production system

Today the final programming of PLC control code is based on function libraries including general reusable functions. The goal is to use the same type of reusable functionality also in early development phases, easily included in early manufacturing design and simulation. In this way the gap between manufacturing design in early phases and control design for PLC control can be significantly reduced.

Simulation can also be used for automatic generation of interlocking states for operation sequences in early phases to get a safe but still optimal behavior for all types of moving devices, including robots but also conveyors, fixtures and clamps.

Including this type of simulation functionality together with formal specification, verification and optimization tools will also simplify the design of efficient product and resource operations taking into account e.g. cycle time, choice of resources, cell layout, material flow, operators' workload, sequence of operations, as well as balancing between different resources within stations and zones.

The suggested concept will support late product changes, but also make it possible to feed back online adjustments in the factory to the engineering platform.

More specifically this project aims at investing:

- How the most recent simulation and automation design tools can be adapted to *simplify the analysis of a complete manufacturing station* (including relevant PLC logics) already in early development phases.
- How simulation and design tools can be combined with *formal verification and optimization* to generate collision free operation sequences as well as optimal cycle time, resource utilization, line balancing and operator work load.
- How simulation tools can be used for specification and generation of all necessary information to enable *automatic generation of PLC programs* by using general function libraries.
- How *complete robot programs,* including all related devices such as weld gun, tip dress etc, can be generated automatically using general program modules.

4. Project realization

Since the scope of the project was very broad and covers all the activities all the way from early design to final commissioning a number of workshops was arranged in order to get a clear picture of the state of the art and also to discuss what lies ahead strategically at the different partner companies. A large number of master thesis projects was defined to investigate different parts of the preparation and also to test newly developed methods. This was done as a mean to include partners in a more active way. PhD students aim was to develop more deep knowledge and produced methods that were then tested in different master thesis projects. Newly developed tools from software partners were also tested and evaluated during the course of this project.

5. Results and deliverables

The project goals as they were described in the application:

1. A reduction of the development and ramp-up time by *complete virtual commissioning* when new manufacturing systems are built or new products are launched in existing manufacturing lines.
2. A reduction of the development time of manufacturing systems by decreasing the number of times information has to be specified, using a *common information platform* through all development phases.
3. More efficient manufacturing systems by applying early *verification and optimization of total behaviour* including all devices within a system.
4. A reduction of the development time by enabling automatic generation of both PLC and complete robot programs.

Planned deliverables were in the application describes as:

- Work flow for complete virtual control preparation
- Methods and software tools for reuse of information (exporting/importing)
- XML-schemas defining required control information (control database)
- General algorithms for sequencing of operations
- Methods and software tools for coordination and optimization of multi-robot-cells including all equipment
- Methods and software tools for optimization of cycle time and plant throughput
- Methods and software tools for automatic generation of PLC control code for station logics in a virtual environment, based on product and process information.
- Methods and software tools for automatic generation of complete robot programs including equipment
- Methods and software tools for verification of larger PLC programs by formal methods
- A physical demonstrator for verification, evaluation and knowledge transfer built at Chalmers
- Industrial PhD students
- Technical reports and publications in journals and at conferences

A reduction of the development and ramp-up time by complete virtual commissioning when new manufacturing systems are built or new products are launched in existing manufacturing lines.

A complete virtual commissioning is different from existing sequential evaluations since it will include:

1. Event based simulation,
2. True kinematics movements of all moving devices including robots,
3. All types of sensors and correct behavior/triggering when activated in the simulation environment,
4. Signal schedule and connections,
5. True time delays of all physical and control equipment, e.g. signal and response delays from PLC equipment,
6. Possibilities to change and influence the events in the simulation in a controlled way to evaluate "what-if" cases.

The result from this project is that a single software solution does not exist today and this technology is still under research and development. By combining several solutions, most parts of complete virtual commissioning could be evaluated.

In the project, a lot of work had to be spent on exporting/importing data from different software tools. With future development, these types of problems are expected to be reduced dramatically.

For the rest of the work, approximately the same amount of working hours have to be spent as in the more traditional way of PLC programming. The main advantages are:

1. Reduced on-line programming and testing in line, approximately 50%. This time is very critical during commissioning and not flexible.
2. Quality assured and complete programs already when the physical commissioning starts.
3. Less mistakes and less time required for adjustment and corrections

A reduction of the development time of manufacturing systems by decreasing the number of times information has to be specified, using a common information platform through all development phases.

The logic information is first created in the Bill-Of-Process (BOP). The logic information will be used in:

1. 3D-simulation tool of robots,
2. Tools for generation of PLC code, HMI interfaces, electrical schematics, etc.,
3. Tools for virtual commissioning of PLC code,
4. The real PLC in physical installation.

Many of these tools are from different companies and there is no driving force to create common interfaces. Solutions could be a common database or standardized file formats, e.g. AML or other XML formats. A solution with one common database does not yet exist.

The project had to extract and import data using either AML or XML formats. CAD data had to be handled using the STEP standard. It is obvious from the project experience that logic and CAD data transfer between systems is one of the major obstacles and time consumer.

It is clear that for a successful virtual commissioning, data transfer work must be reduced to a minimum.

More efficient manufacturing systems by applying early verification and optimization of total behaviour including all devices within a system.

One of the advantages with virtual commissioning is that a much more complete control system can exist in an earlier stage of a project. It gives a lot of benefits.

1. Possibility to evaluate many more alternatives in early stages,
2. Possibility to test new equipment in a virtual environment,
3. Spend more time on optimizing the station to improve robustness and optimize cycle time.

These benefits have been difficult to measure in time and money, however a case study was performed where a three-station line was changed into a two-station line with the total cycle time reduced by 30 % and 50 % reduction of floor space, by applying formal verification techniques and optimization.

Another study was also performed where visualization techniques was applied in a case study that shows that it is possible to extract and visualize operation behavior, which improve the understanding of a specific production solution and its behavior.

A study has also shown that it is possible to minimize the energy consumption during manufacturing of car model. This study focused on the energy consumption of the involved robots and clearly showed that without changing the cycle time of a production station it is possible to minimize the energy consumption.

A reduction of the development time by enabling automatic generation of PLC programs.

A large part of the project was to evaluate how PLC code could be automatically generated from the simulation model using Automation Designer. The result from "Automatic generation of control code for PLC systems (WP4)" was that it was not possible to extract the logic from the simulation model and transfer this to the PLC generation tool in an automatic or easy way using available software`s. The project was not able to solve this issue within the project time frame.

What was shown was that it is possible to generate code that will comply with automotive companies specification without manual intervention. Estimated time reduction would be at least 50 %. Other benefits were that other documentation could be generated from these tools, saving a large amount of work hours. The project was only able to test and verify the HMI generation functionality.

Assuming that the tool in a near future can be completed with a function to read logic from the simulation tool and combine this with the features already existing, extensive amount of the complete and final PLC code could be generated within hours instead of days. Together with the work savings of generating HMI interfaces and electric schematics, the cost saving would be quite big already in one project.

The draw back is that an extensive template library is required and must be created once. The question is how much work is required to do this and what is the maintenance cost. Is this something that can be shared among several companies?

A reduction of the development time by enabling automatic generation of complete robot programs.

The result from "Automatic generation of control code for robot function packages (wp5)" shows that it is possible to automatically read the required information directly from the simulation system. This can replace a manual selection of robot code blocks and be generated within seconds instead of several minutes, per robot function package. The result will also be more error free and the final code could be verified, tested and controlled in earlier phases of the project. This methodology gives fewer errors that have to be solved and adjusted in a final phase where time is very critical.

Considering a project with approximately 100 robot function packages and most of them are handling types, the time could be reduced from 2-3 days to a few hours. If also the errors are reduced from a 10% adjustment to less than 1% adjustment, there will be another days saving. This time is very important since this is then part of the on-line commissioning, which is limited.

5.1 Delivery to FFI-goals

The project aimed at contributing to the program's overall goal within production preparation and production:

- 40% increase in productivity within the area of production preparation

  A reduction of the development time by enabling automatic generation of PLC programs.

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  A reduction of the development time by enabling automatic generation of complete robot programs.

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  More efficient manufacturing systems by applying early verification and optimization of total behaviour including all devices within a system.

  Another study was also performed where visualization techniques was applied in a case study that shows that it is possible to extract and visualize operation behavior, which improve the understanding of a specific production solution and its behavior.

- 30% increase in productivity in the production process.

  More efficient manufacturing systems by applying early verification and optimization of total behaviour including all devices within a system.

  A case study was performed where a three-station line was changed into a two-station line with the total cycle time reduced by 30 % and 50 % reduction of floor space, by applying formal verification techniques and optimization. Another study was also performed where visualization techniques was applied in a case study that shows that it is possible to extract and visualize operation behavior, which improve the understanding of a specific production solution and its behavior.

- 30% decrease of the environmental influence of the production processes

  More efficient manufacturing systems by applying early verification and optimization of total behaviour including all devices within a system.

  A study has shown that it is possible to minimize the energy consumption during manufacturing of a car model. This study focused on the energy consumption of the involved robots and clearly showed that without changing the cycle time of a production station it is possible to minimize the energy consumption.

6. Dissemination and publications

6.1 Knowledge and results dissemination

Being able to perform a complete virtual preparation and commissioning comes with a big opportunity to realize an efficient preparation of productions systems and efficient production systems. As the software and tools have become more powerful this is now focus area for many industry sectors as well as within the academia.
The knowledge and lessons learnt have been constantly disseminated towards both the industry and academia. Related projects where partners are involved have been approached in order to compare approaches and knowledge both national as well as international projects, for instance; LISA (FFI national), Know4Car and MyCar (EU-projects). The project have also approach a large number of companies and presented the ideas and result.

6.2 Publications

Master thesis

[1] Sathyamyla Kanthabhabhajeya, Ruben Eduardo Pabello, Rodriguez Automatic generation of control code for robot function packages. Generation of robot set-up descriptions based on data in the simulation. Master thesis, Department of Signals and Systems, Chalmers University of Technology, ISSN 99-2747920-4; nr EX020/2010. Involved companies: KUKA, Volvo Cars, Siemens, Chalmers

[2] Daniel Wahlberg, Zhang Yixian, Automatic generation of control code for robot function packages. Master thesis, Department of Signals and Systems, Chalmers University of Technology, ISSN 99-2747920-4; nr EX093/2010. Involved companies: KUKA, Volvo Cars, Siemens, Chalmers

[3] Mikael Andersson, Erik Helander, Automatic generation of PLC programs using automation designer. Master thesis, Department of Signals and Systems, Chalmers University of Technology, ISSN 99-2747920-4; nr EX063/2010. Involved companies: Siemens, Volvo Cars, Chalmers

[4] Muzaffar Ahmad, Enrique Garcia Ruiz, Virtual preparation of automation station at Volvo Trucks using Delmia solutions. Master thesis, Department of Signals and Systems, Chalmers University of Technology, ISSN 99-2747920-4; nr EX078/2010. Involved companies: Volvo Truck, Dassault Systemes, Chalmers

[5] Nina Sundström, Automatic generation of operations for Flexa production system. Master thesis, Department of Signals and Systems, Chalmers University of Technology, ISSN 99-2747920-4; nr EX024/2010. Involved companies: Volvo Aero, Chalmers.

[6] Johan Lindqvist, August Rydberg, Energy optimization of robot cells. Departments of Signals and Systems, Chalmers University of Technology, ISSN 99-2747920-4; nr EX059/2010. Involved companies: Chalmers, ABB

[7] Andreas Larsson, Henrik Nilsson, Visualize an event-based simulation model made in Process Simulate. Master thesis, Department of Signals and Systems, Chalmers University of Technology, ISSN 99-2747920-4; nr EX044/2011

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Involved companies: Volvo Cars, Chalmers, Siemens

[8] Umair Qadeer, Muhammad Sualeh, Automatic coordination and collision avoidance using sequence planning and process simulate. Master thesis, Departments of Signals and Systems, Chalmers University of Technology, ISSN 99-2747920-4; nr EX071/2011

Involved Companies: VCC, Chalmers, Siemens.

[9] Emil Åkesson, Virtual preparation of advanced production system. A case study for body-in-white industrial applications. Master thesis, Departments of Signals and Systems, Chalmers University of Technology, ISSN 99-2747920-4; nr EX096/2010.

Involved companies: Scania, Chalmers, Dassault Systemes.

[10] Oliver Salamon, Ali Heidari, Virtual commissioning of an existing manufacturing cell at Volvo Car Corporation using DELMIA V6. Master thesis, Departments of Signals and Systems, Chalmers University of Technology, ISSN 99-2747920-4; nr EX023/2012

Conference proceedings

[11] Falkman, Petter; Göransson Hedvall, Jonathan; Holmblad, Anders; Lennartson, Bengt: Vendor independent control database for virtual preparation and formal verification. *International Conference on Information and Automation, ICIA 2011; Shenzhen; 6 June 2011 through 8 June 2011*, pp. 851-857. ISBN/ISSN: 978-145770268-6

[12] Patrik Magnusson, Nina Sundström, Kristofer Bengtsson, Bengt Lennartson, Petter Falkman, Martin Fabian, Planning transport sequences for flexible manufacturing systems. Proceedings of the 18th IFAC World Congress, 2011, Milano, 28 August - 2 September 2011, ISBN/ISSN: 978-3-902661-93-7.

[13] Petter Falkman, E. Helander, M. Andersson, Automatic generation: A way of ensuring PLC and HMI standards. IEEE 16th Conference on Emerging Technologies and Factory Automation, ETFA 2011, Toulouse, 5-9 September 2011, ISBN/ISSN: 978-145770018-7.

[14] Zhennan FEI, Sajed Miremadi, Knut Åkesson, Bengt Lennartson, Efficient Symbolic Supervisory Synthesis and Guard Generation: Evaluating partitioning techniques for the state-space exploration. ICAART 2011 - Proceedings of the 3rd International Conference on Agents and Artificial Intelligence, p. 106-115, ISBN/ISSN: 978-989842540-9, 2011.

[15] Alberto Vergnano, Carl Thorstensson, Bengt Lennartson, Petter Falkman, Marcello Pellicciari, Chengyin Yuan, Stephan Biller, Francesco Leali, Embedding detailed robot energy optimization into high-level scheduling. Proc. of the IEEE International Conference on Conference on Automation Science and Engineering, Toronto, Canada, August 21-24, 2010.

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[18] Shoaei, Mohammad Reza, Feng, Lei, Lennartson, Bengt, Abstractions for Nonblocking Supervisory Control of Extended Finite Automata. 8th IEEE International Conference on Automation Science and Engineering, August 20-24, 2012, Seoul, Korea.

[19] Kristofer Bengtsson, Bengt Lennartson, Chengyin Yuan, Petter Falkman, Stephan Biller, Operation-Oriented Specification for Integrated Control Logic Development. 2009 IEEE Conference on Automation Science and Engineering, CASE 2009, Bangalore, India, p. 183-90, ISBN/ISSN: 978-1-4244-4578-3, 2009.

[20] Submitted article to conference Based on robot code generation.

Journal publications

[21] Petter Falkman, Erik Helander, Mikael Andersson; Automatic Generation: A way of ensuring PLC and HMI standards. Invited to be submitted to Journal of Mechanics and Automation Engineering, 2012.

[22] Bengt Lennartson, K. Bengtsson, C. Y. Yuan, Kristin Andersson, Martin Fabian, Petter Falkman, Knut Åkesson, Sequence Planning for Integrated Product, Process and Automation Design. IEEE Transactions on Automation Science and Engineering, 7 (4) p. 791-802 ISBN/ISSN: 1545-5955, 2010.

7. Conclusions and future research

This project has made it possible to deeply explore all aspects of a future procedure and evaluate tools currently available within the area of logic preparation and simulation. Thanks to many of the suppliers, we have been able to work with tools and processes long before they have been officially released on the market.

During the period of this project, the members of the automotive industry, were able to investigate many, diversified work methods and tools. It would have not been possible without the support and resources made available from the projectand FFI.

Following areas have been explored and evaluated:

- Automatically generate sequence code and set-up for robot handling and process systems
- Generation and transfer of logical behaviour between systems.
  Understand how XML and AML protocols can work and what information can be contained in the various protocols.
- Test and evaluate different procedures to extract logical information from currently available simulation systems. However, this was one of the key goals from Volvo Car Corporation and this was also one goal not completed. This was to technical limitations in current systems.
- Visualisation of early logical solutions to easily share and explain sequences to all parties involved.
- Study the possibilities to automatically generate HMI, electrical drawings, etc. Potential cost and time savers in a near future.
- Create model of a multirobot station to reduce floor space, energy and increase the efficiency of current stations. It was possible to do this and prevent collisions, even though many overlaps existed.
- Make a deep dive into the limitations of performing virtual commissioning of an existing station using modern simulation tools.
- Start the evaluation of coming virtual commissioning tools and the consequences.

All this has become the base for Volvo Car Corporation to start to create a strategy and work procedure for future robot systems combined with other equipment and electrical sequences. This is a must to be able to reduce the lead times in the future with up to 50%. A necessity to be able to compete in the automotive business.

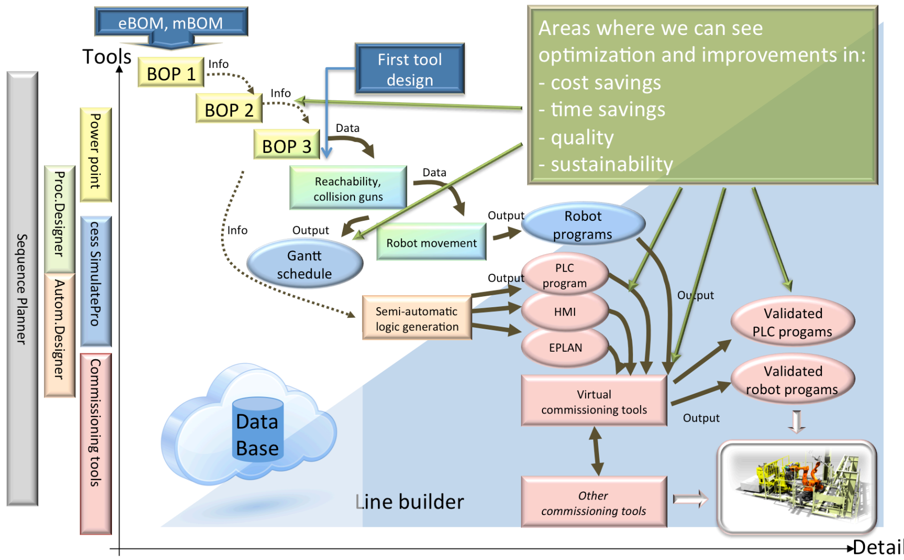

Figure 5 Identified areas where optimization and improvements with in the area of virtual preparation and commissioning can be achieved.

8. Participating parties and contact person

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