RESEARCH REPORT

VTT-R-03753-11

Computational Models in Product Life Cycle – Codes:

Overview to the Codes Project

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Confidentiality: Public

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Overview to the Codes Project	
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Summary

This report collects the history and the milestones of the Codes research project, briefly introduces the product deliverables, and discusses about the project implementation, outcome, and the lessons learned. The report does not provide a deep analysis of the results of each project task. That would have been far too difficult task in the given schedule, due to the wide scope and heterogeneous content of the project. Some conclusions about the findings and trends are provided together with discussion about the future work.

The result and success of the Codes project can be said to be good based on the project deliverables and the understanding of the subject that was gathered during the project. But the most important outcome of the project was that there is definitely room for the further research on the fundamental research topics of the project: simulation and design tool integration in the product process and the management of the simulation-based product life cycle process.

Confidentiality	Public

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1 Introduction

Application of computational methods has become a standard approach in business, in engineering, and in other parts of running business, as well as in scientific and applied research. Modelling and simulation of systems, numerical data analysis, and computer visualisation are common tools in product development, but also in business and product life cycle management. In engineering design, computational methods have been used already for decades, including system simulation, finite element analysis, and computational fluid dynamics, to mention few examples. For all major engineering and computational domain, there are plentiful options for computational tools and even methods. This indicates that the availability of computational methods and tools implementing these methods is not limiting the progress in their application. Indeed, signals from users, both in research and product development field, indicate that matters, such as data transfer between software applications, software co-operation, and data management in general, are becoming the bottleneck for the progress. This was the frame for the project *Computational models in product life cycle – Codes*, a research project in Tekes *Digital product process* research programme.

This report collects the history and the milestones of the Codes research project, briefly introduces the product deliverables, and discusses about the project implementation, outcome, and some of the lessons learned. The report does not provide a deep analysis of the results of each project task. That would have been far too difficult in the given schedule, due to the wide scope and heterogeneous content of the project.

2 Project contents and implementation

2.1 Project organisation

The project was executed by four separate research parties:
- Aalto University, the School of Science and Engineering (in the beginning of the project, Helsinki University of Technology).
- Lappeenranta University of Technology,
- Tampere University of Technology, and
- VTT Technical Research Centre of Finland.

The project had co-operation with the Linköping University, Sweden. The funding for the project was provided separately for each of the research parties, thus the project was organised into four separate subprojects having a common general project plan. In addition to the research parties, the following organisations participated the project:
- ABB Oy Marine (funding),
- Alstom (Switzerland) Ltd. (funding),
- Comos Industry Solutions ApS (software),
- CSC – IT Center for Science Ltd. (steering committee participation),
- Fortum Nuclear Services Oy (funding),

- Intergraph Finland Oy (software),
- Nokia Oyj (funding),
- PSK Standardisointi (funding),
- Tekes (funding),
- Teollisuuden hajautetun tiedonhallinnan yhdistys THTH ry (funding), and
- Wärtsilä R&D (funding).

The project was coordinated by VTT Technical Research Centre of Finland, and Chief Research Scientist, Dr. Olli Ventä was the responsible director of the project.

2.2 Project contents

The project was organised in five main tasks that covered the research work of all the research parties. The main tasks were:

1. Management and administration
2. Applying semantics modelling and standardisation in integration of process simulation and plant design
3. Model-based machine system development
4. Product life cycle simulation
5. Dissemination

The management and administration task was reserved for project management work. The actual research work was done in main research tasks, and the work for disseminating the results of the project was organised in dissemination task. The project tasks and subtasks together with their descriptions are presented in *Appendix A: Project contents*, in more detail.

Even though the project had common research plan for all the research parties, the funding for the project was provided separately for each of the research parties. Due to this, it was natural that each research parties decided internally the details for their subproject. In some of the subtasks of the project, there was practical cooperation in research work. The research content via the results of the work is described in separate research reports and publications. These are listed briefly in section 3, *Results and deliverables*.

2.3 Dissemination

Dissemination of the research results during the research project is important. Getting research results already during the project is one of the advantages the participating organisations get from funding the project. Dissemination is also mandatory for spreading the new knowledge and understanding in the project. Project internal dissemination can be done in several manners, e.g. using project internal website, arranging project seminars and workshops, and publishing results in project reports. For the research parties (e.g. universities and research institutes), public dissemination is often important already during the project execution. For this, scientific journals and conferences, and scientific theses are the major publication channels.

The Codes project arranged and co-arranged the following seminars and workshops:

- **Seminar on Industrial Information Management;**
  THTH ry, VTT. Mar 24, 2009
- **Seminar on Product Life Cycle Management and eMaintenance;**
  VTT, May 12, 2009
- **Seminar on Teollisuuden tietosisältöjen hallinta;**
  organised together with Sefram project. November 17, 2009
- **Developers' seminar on Application of ISO 15926 in Finnish Industry;**
  Helsinki University of Technology, November 17, 2009.
- **The 1st Codes Workshop;**
  VTT, March 24, 2010
- **The Spring Seminar of the THTH association and the Codes project;**
  A joint seminar with THTH association and Codes project, May 5, 2010
- **Codes Seminar;**
  VTT, November 23, 2010.
- **The Spring Seminar of the THTH association and the Codes project;**
  A joint seminar with THTH association and Codes project, May 10, 2011.

The seminars and workshops were the events to disseminate the results of the project while the project was still running. They also provided a natural occasion for dialog between the research parties and the other participating organisations.

To disseminate the project results to the participating organisations and to encourage to project parties to discuss about the research topics, the project organised internal content meetings:

- **Codes Content meeting 1**, September 8, 2009.
- **Codes Content meeting 2**, January 11, 2010.
- **Codes Content meeting 3**, May 17, 2010.
- **Codes Content meeting 4**, September 13, 2010.

The co-operation with Linköping University was implemented mainly with two visiting periods of Professor Peter Fritzson from at VTT:

- 1st visiting period at VTT, March 23–29, 2009, and
- 2nd visiting period at VTT, September 7–13, 2009.

During the first visit to VTT Professor Fritzson gave an open lecture at Helsinki University of Technology on *Model-driven development supported by High Level Mathematical Modeling and Simulation with Modelica and OpenModelica*. The lecture was given on March 26, 2009.

3 Results and deliverables

The project produced research deliverables in forms of research reports, journal and conference articles, posters, standard proposals, and software implementations. Based on the number of deliverables, the project was quite productive. The document formed deliverables for the project are listed below. The software implementations have been demonstrated in the project seminars and workshops using recorded videos.

3.1 Task 2: Applying semantics modelling and standardisation in integration of process simulation and plant design

Below are listed the deliverables of the task 2. Project seminar and workshop presentations are not listed here. The presentation material has been delivered via project's internal website after each event.

Paljakka, M.
The CEN ORCHID Roadmap Standardising Information Across the Plant Engineering Supply Chain - Part 1: Direction and Framework.
CEN Workshop Agreement (together with the European Committee for Standardization CEN), 2010. 44 p. (Report CWA 16180-1:2010).

Paljakka, M., Mätäsniemi, T., Luukkainen, M. & Karhela, T.
Creating Process simulation Models out of Engineering Data using Sefram and Simantics Platforms.
(Scientific article. In progress).

Abstract: The value of process simulation is generally acknowledged in the industry. Simulation provides a platform for development, testing and training in a virtual environment with no need to interfere with the use of the actual facility. This brings about obvious economic and safety benefits.
The better availability of good quality data in an early phase of a project can be expected to make process simulation more popular. Simulation will support the decision making in each activity and improve the knowledge transfer across the network.

A possible bottleneck is the availability of as-is models of existing plants. The Sefram project has however demonstrated the integration of plant data from different sources, and as a next step plant owners could build up as-is models of their plants to form a foundation for novel collaboration.
This article presents ways in which process simulation can be used in the value network related to the plant life cycle. The use of the Sefram infrastructure in different phases is analysed, and an example is given about the transfer of an engineering model into a process simulation model.

Keywords: process industry, information exchange, engineering, process simulation

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Vepsäläinen, T., Hästbacka, D. & Kuikka, S.
Transforming UML AP to ModelicaML.
Tampere, Tampere University of Technology, 2010. 40 p. (Working report).

Abstract: Modelica is an object-oriented modeling language for describing ordinary and differential algebraic equation systems combined with discrete events. These kinds of models suit ideally for representing physical behaviour and the exchange of energy, signals and continuous-time interactions between systems, such as, controlled process plants consisting of a process plant and a control system.

ModelicaML is a UML profile enabling the definition of Modelica models by exploiting the graphical modeling capabilities and intelligibility of UML. UML Automation Profile, on the other hand, enables functional modeling of automation and control applications on both platform independent and platform specific levels. The aim of this work is to integrate these modeling languages together in order to enable early simulation controlled industrial manufacturing processes and to facilitate control system development.

Vepsäläinen, T., Hästbacka, D. & Kuikka, S.
Simulation Assisted Model-Based Control Development – Unifying UML AP and Modelica ML.
11th International Middle Eastern Simulation Multiconference, Alexandria, Egypt, December 1–3, 2010. pp. 43–50.

Abstract: Dynamic simulators and simulation models could support in several ways the development of industrial automation and control systems. Despite the benefits, simulation models are not always used because of the amount of work that is required for developing sufficiently accurate models. In this paper, we present an approach to transform functional UML Automation Profile (AP) models of control applications to ModelicaML and finally to Modelica models. This facilitates model-driven control system development by enabling early simulation of controlled manufacturing systems that consist of dynamic models of both manufacturing systems and control systems. In this way, models originally created for the purpose of model-driven development of control applications can be used as parts of simulation models so that the amount of required simulation model development work can be reduced. The paper presents both the concept of a transformation and the technical foundation based on which the transformation has been implemented. An example of utilization of the transformation and tools in development of a simulation model is provided, too.

Keywords: UML AP, control systems, Modelica, simulation, transformation

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Vepsäläinen, T., Hästbacka, D. & Kuikka, S.
Simulointiavusteinen mallipohjainen automaatiosovelluskehitys.
The Automaatio XIX seminar in Helsinki 15.–16.3.2011. Tampere, Tampere University of Technology, 2011. 6 p. (Seminar article).

Tiivistelmä: Automaatiojärjestelmien ja -sovellusten kehitys ovat tehtäviä, joita voidaan merkittävästi tehostaa simulointitekniikoita käyttäen. Automatisoitua kokonaisjärjestelmää kuvaavien simulaattorien kehitys on kuitenkin todettu vaativaksi ja aikaa vieväksi tehtäväksi, mikä vähentää simulaattorien teollista hyödyntämistä. CODES-projektissa tehdyn tutkimuksemme lähtökohta oli, että vastaavasti kuin mallipohjaisia suunnittelumenetelmiä hyödyntäen on mahdollista tuottaa automaattisesti osa suoritettavasta ohjaussovelluksesta, on myös suoritettavien simulointimallien tuottaminen mahdollista mallien tietosisällön perusteella. Erityisesti ModelicaML-profiiliin perustuvien simulointimallien tuottaminen katsottiin houkuttelevaksi vaihtoehdoksi, koska ModelicaML perustuu samoihin avoimen lähdekoodin työkaluihin kuin AUKOTON-projektissa kehittämämme UML AP -työkalu. Täten simulointimallien luonnissa voitaisiin hyödyntää mm. standardoituja transformaatiokieliä ja niiden avoimen lähdekoodin toteutuksia Eclipse-ympäristössä. Tämä työ esittelee konseptuaalisen transformaation UML-automaatioprofiilin mukaisista toiminnallisista malleista ModelicaML-simulointimalleiksi sekä esittelee toteutukseen liittyviä tekniikoita ja kieliä, kuten UML, Modelica, ModelicaML ja QVT. Toteutettua transformaation prototyyppiä hyödynnetään myös koko automatisoitua järjestelmää kuvaavan suoritettavan simulointimallin generoimisessa perustuen automatisoitavaa prosessia kuvaavaan ModelicaML-malliin ja ohjausohjelmiston toiminnalliseen UML AP -malliin.

Avainsanat: UML AP, automaatiosovellukset, Modelica, simulointi, transformaatio

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Hästbacka, D.
Transformation Approaches for Unifying UML Based Models and OWL Ontologies.
Tampere, Tampere University of Technology, 2010. 12 p. + app. 1 p. (Research report).

Abstract: This report studies implementation methods for extraction of a domain ontology and instance model from a UML modelling language, namely the UML Automation Profile. Transformations of the modelling language metamodel and instance model to domain ontologies and instance models are being studied. The emphasis of this study is on generating instance models and on an approach that does not necessarily require the Eclipse environment for execution. The ontological representations resulting from these transformations could then be used in classification and reasoning in management of information in UML (MOF) based models.

Hästbacka, D. & Kuikka, S.
Bridging UML Profile Based Models and OWL Ontologies in Model-driven Development – Industrial Control Application.
3rd International Workshop on Future Trends of Model-Driven Development (FTMDD 2011), in conjunction with the 13th International Conference on Enterprise Information Systems (ICEIS 2011), Beijing, China, 8–11 June, 2011.

Abstract: Model-driven development is considered to improve productivity and quality in software application development. The increasing complexity in models and the number of modeling methods used requires new approaches for knowledge management to make the handling of models easier both during design and run-time. Modeling in MDD shares characteristics with ontology development. This paper discusses UML based models used in MDD and their relationship to OWL ontologies. A concept is proposed how to create ontologies corresponding to these models and how they can be used concurrently in supporting the application development. The main principle of the approach is the distinct separation of knowledge in the domain model and model instances. As a result the instance model transformations can be kept simple and corresponding ontology representations of application models can be used to support the development. Applications of the approach to model-driven development and engineering of industrial control applications are also discussed.

Laakso, P.
Simulation model initialisator.
Espoo: VTT, 2011. 11 p. (Research report VTT-R-03374-11).

Summary: This report has been generated in project called CODES – Computational Models in Product Life Cycle, where it belongs to Task 2 that concerns applying semantics modelling and standardisation in integration of process simulation and plant design. The work was done in subtask 2.4 where possibilities to do design system and simulation integration through standard solutions were investigated. ”. It has been focused to the Case 1: Simulation model initialiser.
In this case a demonstration program was developed to create state initialisation file for Apros dynamic simulator program. This program was used to check and develop the methods needed for generating initialisation files.
The tool uses the initial state definitions and uses them to extrapolate the new state of the simulation model. The nominal or source state is used to find out the scaling of the state e.g. how much larger or smaller the flow were in the source state when compared to target.
The methods presented here are only needed when used with physically realistic complex simulation systems. They’re typically computationally complex so that running them between states takes typically a long time and they contain lot of state variables that need to be stored. Also the simulation models need to be relatively often changed and still has lot of possible initial states.

Keywords: simulation, initialisator, Apros, information exchange

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Mätäsniemi, T.
Tacton-Simantics information exchange.
Tampere: VTT, 2011. 28 p. (Research report VTT-R-03373-11).

Summary: This report has been generated in a project called CODES – Computational Models in Product Life Cycle where it belongs to Task 2 that concerns applying semantics modelling and standardisation in integration of process simulation and plant design. The work was done in subtask 2.4 where possibilities to do design system and simulation integration through standard solutions were investigated. ”. It has been focused to the Case 2: Connecting system dynamic models to product configurator.
Data transfer is needed to make it possible to evaluate effects of a valid product configuration solution to workflows and also to take into account feedback of workflow experiments in the product configuration.
During the project prototype solution was generated and analyzed. This report describes the experiences gained from generating the prototype. In the prototype Tacton product configurator is connected to Simantics system dynamic simulation tool. Both products are described and 3 different approaches for data transfer are introduced and considered. The best approach varies depending on the properties chosen and their importance. Properties are maintainability, comprehension and clarity, reliability, usability and efficiency. The prototype implementation follows approach where only for limited set of Tacton concepts the meta principles are modelled. In addition, the information content is reduced to make the technical solution more flexible and maintainable. The results are promising and there is a

clear need for this kind of integration. However, more intelligent and semantics algorithms have to be developed in the future.

Keywords: system dynamics, product configuration, information exchange, ontology, Simantics

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PSK 5965.
XML Data Transfer. Equipment Classes and Subclasses.
2nd edition. PSK Standards Association. 2010.

PSK 5981.
Data Transmission. Data Element Dictionary.
Appendix for PSK 5965 Data Transfer. Equipment Classes and Subclasses. 2nd edition. (In progress).

Aarnio, P.
Harmonization of Plant Model Standards – Semi-automatic comparison of PSK industry standards with ISO 15926-4.
Espoo: Aalto University, 2010. 44 p. (Research Report).

Preface: This report documents the work that has been done in subtask 2.5 of the work package 2 of CODES Tekes project. The target of this task according to the project plan was to compare Finnish national classification standards of PSK and ISO 15926-4. This task is part of the standard harmonization work that has been started in PSK Standardization and that will still continue in PSK59/5 technical committee after this CODES task has been completed at the end of the year 2010. This document focus mainly on presenting the first phase of the harmonization process, that is, the automated comparison phase that was carried out with a software tool developed for this task. The details of the applied algorithm have been described only in this document and consequently the information provided in this report is necessary for understanding the operation of ElementMatcher tool. The output of this tool is a so called alignment set that records all the found correspondence relations between the elements of PSK standards and ISO 15926-4, Reference data. A summary of these comparison results is presented in this report. The final harmonization results can be provided only for one standard, PSK5965, Equipment classes and subclasses, because the second phase of the harmonization process, manual analysis phase, has not yet been completed in PSK59/5 TC for the other PSK standards selected to be harmonized.

Aarnio, P. & Koskinen, K.
Harmonisation of Plant Model Standards – Semi-automatic comparison of PSK industry standards with ISO 15926-4.
Poster in CEN-Orchid/PROLIST Conference, May 19–20, 2010, Monheim, Germany.

Aarnio, P. & Koskinen, K.

A Lightweight Element Matching Method for Industrial Terminology Harmonization Exploiting Structural Information Based on Naming Conventions.
International Conference on Knowledge Engineering and Ontology Development (KEOD 2011). (Scientific article. In progress).

3.2 Task 3: Model-based machine system development

Below are listed the deliverables of the task 3. Project seminar and workshop presentations are not listed here. The presentation material has been delivered via project's internal website after each event.

Kortelainen, Klinge, P. & Katajamäki, K.
Open Source Software for Engineering Applications.
Espoo: VTT, 2010. 48 p. (Research report VTT-R-03493-10).

Abstract: A short survey of the present status of open source software for engineering applications was conducted. The focus was mainly on the finite element method (FEM) and the control volume method (CVM) tools used for structural analysis, multi-physics and fluid flow simulation. Several open software tools were shortly described (FeniCS, Gmsh, SALOME, OpenDX, ParaView, VisIt, Octave, OpenModelica, Scilab, SciPy, NumPy, Simantics) and a couple of CVM and FEM packages were evaluated in more detail (Code_Saturne, OpenFOAM, Code_Aster, Elmer).

In general open source softwares show great potential for commercial use though some softwares are still in an early development phase. However, many of open source applications are maintained and developed by commercial companies for their own use. This increases the trust for the quality of the software and makes them more attractive for industrial use.

Keywords: engineering, open source, software

Rantalainen, T. & Kortelainen J.
Managing of Off-Line and Real-Time Multibody System Models.
Lappeenranta, Lappeenranta University of Technology, 2010. 12 p. (Research report).

Kortelainen, J. & Mikkola, A.
Semantic data model in multibody system simulation.
Proceedings of the Institution of Mechanical Engineers, Part K: Journal of Multibody Dynamics, 224(4), 341–352, 2010. DOI: 10.1243/14644193JMBD257.

Abstract: This article introduces an approach for using a semantic data model and knowledge representation technologies in the data management of multibody system simulation. This is accomplished by developing a semantic ontology for multibody system modelling. As an example of semantic ontology modelling, the

introduced approach is applied to a simple double-pendulum model. The purpose of the example is to demonstrate that multibody system simulation data can be expressed using semantic data representation. In addition, semantic data representation enables a general and straightforward application integration solution for design tools and other information systems typically involved in the industrial product design process. It is also important to note that this approach enables knowledge of the domain of interest to be stored together with the modelling data. By including rules and constraints with the data and applying a semantic reasoning methodology, the apparent intelligence of the stored data is increased.

Keywords: multibody application, data management, semantic data model

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Kortelainen, J.
Semantic data model for multibody system modelling.
Lappeenranta, Lappeenranta University of Technology, 2011. (Doctoral thesis. In progress).

Kortelainen, J. & Mikkola, A.
Semantic Restrictions and Rules in Multibody System Modelling.
(Scientific article. In progress).

Kortelainen, J., Klinge, P. & Katajamäki, K.
Managing Mesh-Based Data in a Semantic Database.
Espoo: VTT, 2011, 29 p. (Research report VTT-R-03154-11).

Abstract: Several numerical methods, such as finite difference method, finite element method, and control volume method, use spatial discretisation for estimating spatial differentials. Common to these methods is that they estimate continuous volume with discrete finite volumes or nodes. Use of semantic data model is an attempt to unify the representation of modelling data in computational systems.

The objective of this work is to create a generic and comprehensive description of spatially discretised geometric model usually called a mesh. The semantic representation should be applicable to different numerical computational methods and modelling domains. The fundamental objective is to enable the use of different tools like finite element analysis and computational fluid dynamics tools to access mesh data from a common semantic database. The emphasis on this representation development is on minimising the amount of data that is needed to store explicitly for a computational mesh and all data that is needed to run a computation.

This study shows that spatially discretised data can be represented in semantic form and that there are several approaches for representing the data. The fully semantic approach provides the most flexible data model from semantic point of view by allowing semantic reasoning in single element level, due to semantic representation of each of the nodes and elements of the mesh. On the other, the fully semantic approach is also the most resource intensive and is probably too inefficient for industrial applications. An approach between fully semantic data representation and plain tabular data was selected as the best compromise for the data model.

Keywords: modelling, simulation, mesh, CFD, FEM, semantic, format

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3.3 Task 4: Product life cycle simulation

Below are listed the deliverables of the task 4. Project seminar and workshop presentations are not listed here. The presentation material has been delivered via project's internal website after each event.

Valkokari, P.
Product reliability and availability in product life cycle.
Tampere: VTT, 2011. 21 p. + app. 71 p. (Research report VTT-R-00198-10).

Summary: This report is a part of the project called CODES – Computational Models in Product Life Cycle and there it belongs to task 4, which aims to outline and define a simulation-based approach, i.e. product life cycle simulator. This document presents results of the study of how product reliability and availability issues should be taken into a consideration during product life cycle.
Product Life Cycle Simulator must in general support the reliability management during product life cycle. It should support decision making in cost-efficient and practical way, when the impacts of different solutions will be compared. Therefore the specification and requirements of reliability and availability issues as a part of PLCS should support in finding the answer for following questions:

- What is the appropriate life cycle model for the product in question?
- What are required RAMS tasks during product life cycle?
- What are responsibilities when carrying out these RAMS tasks?
- What are the necessary instructions, tools and reference documents when executing these RAMS tasks?

Although the study was carried out in quite a robust way, it showed that there exists high number of methods to model product reliability during its life cycle. Often these methods are used by the reliability experts. This means that the challenge in definition of PLCS specification is not the lack of reliability related data or methodology but on the contrary, it is in finding the most applicable data and methods. The conclusion is that for specifying PLCS, it would be necessary to have a defined product case before the reliability and availability management simulation tool and the required procedures to use the tool could be specified.
Keywords: reliability, RAMS management, product life cycle

Anttila, A.
Enivironmental analysis, sustainability, product life cycle.
Espoo: VTT, 2011. 21 p. (Research report VTT-R-00164-11).

Summary: This report is a part of the project called CODES – Computational Models in Product Life Cycle and there it belongs to task 4, which aims to outline and define a simulation-based approach, product life cycle simulator, to evaluate

the life cycle of a product at the same time from the viewpoint of the environmental load and the profitability of a company's business.

This document is a study of how environmental influences should be taken into consideration during product life cycle. In this report the objective is to describe what aspects of environmental influences should be taken into consideration when the product life cycle simulator will be specified.

The report cannot cover all the possible aspects or references related to environmental influences and sustainability issues during the life cycle of a product. The approaches that will be presented are collected from the sources of knowledge that are mentioned in the text. These sources are basically scientific articles, standards and results from previous research projects.

The product environmental life-cycle information should be already collected in parallel with the design of the product. However, this is often difficult because of the complexity of the product's life-cycle. The information which is needed for environmental analysis is composed of material and energy flows and the information about their impact on the environment.

Keywords: environmental analysis, sustainability, product life cycle

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Heikkilä, A.
Business Model in Product Life Cycle.
Tampere: VTT, 2010. 22 p. + app. 1 p. (Research report VTT-R-04354-10).

Summary: This literature review presents what kind of aspects (e.g. business model requirements and specifications) and information (e.g. input and output information) should be included in determining the business model of a product in product life cycle simulation (PLCS).
In the beginning, the review presents the basic idea of the business model. According to Seppänen (2008) the business model is defined as a generic term to describe the logic of what a firm does and how it does it. The review describes the basic idea of different generic business models and the competitive advantage of each of them. The review summarizes some common frameworks for the design and formulation of a business model. These frameworks showed alternative and complementary view points to define the business model and its component.
Summarized, the specification and requirements of business model issues as a part of PLCS should support in finding the answer for the following questions:

- What are the core capabilities of a business model and what kind of costs these capabilities incures?
- What is required for the supply network, partners, distribution channel, and customer relationship? And what kind of costs these incure?
- What is the value proposition of a business model?
- What are the key performance measurements of the business model?
- What information and other aspect are the necessary instructions, tools and reference documents to execute these business model aspects?

A properly tailored business model has great power and can serve as an essential strategic tool for the enterprise but there are also some common problems which have to be noticed.

Keywords: business model, core capability, business cost, business profit

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Ruutu, S. & Riihimäki, P.
Operation process modelling in management services.
Espoo: VTT, 2010. 11 p. (Research report VTT-R-00921-10).

Summary: This report is part of the project CODES – Computational Models in Product Life Cycle (Task 4) which aims to outline and define a simulation-based approach to product life cycle management.

The document begins with an overview of the use of simulation in operation and business processes as a tool to guide managerial decision making. Several modelling and simulation approaches are presented. The benefits of operation process modelling for different views of the product life cycle simulator (PLCS) are discussed as well as the benefits for the analysis of different product life cycle stages. The life cycle stages analysed are product development, usage and usage support, and product retirement and disposal. The product life cycle is analysed from environmental, business, as well as reliability and availability aspects.

Currently, there are various separate methods to analyse different aspects of a product's life cycle. The aim of the product life cycle simulator is to integrate the different types of analyses into a single tool.

Keywords: simulation, decision support, operation process, business process

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Jantunen, E., Valkokari, P., Ruutu, S., Heikkilä, A:, Riihimäki, P. & Anttila, A.
Product Life Cycle Simulator RoadMap.
Espoo: VTT, 2011. 40 p. (Research report VTT-R-00165-11).

Summary: The purpose of this document is to define a "Product Life Cycle Simulator RoadMap 2015" aiming at defining the development that will take place within the next five years. The authors understand the wideness of the subject and how challenging it is to try to describe everything that is related to Product Life Cycle Simulation (PLCS). Probably a work like this would never be completed unless simplifications are made and the authors only hope that they been able to describe the subject in some acceptable balance i.e. without forgetting any important subject and without going too much in detail with some other subject. The introduction of the paper gives a short description of the current status as the authors see it in Finnish Manufacturing Industry. The following chapters cover various angles of PLCS and try to indentify the future development in that specific area. In the last chapters a summary of trends is listed and a synthesis is given as a foundation of the Product Life Cycle Simulation RoadMap 2015.

Keywords: Life Cycle Engineering, Sustainability, Reliability, System Dynamics

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Jantunen, E., Ruutu, S. & Valkokari, P.
Product Life Cycle Simulation.

Proceedings of the 12th International MITIP Conference on Information Technology & Innovation Processes of the Enterprises, 29–31 August, 2010, Centre for Logistics, Aalborg University, Denmark. pp. 220–229.

Abstract: Product Life Cycle Simulation has become a very interesting subject and the capability of handling the Life Cycle has become a strategic issue for companies in the manufacturing industry. This trend has been noticed within European Union and the possibilities it has given for the industry to keep up competitive in the global world market have not stayed unnoticed. Especially, the importance of studying the whole Life Cycle and all the phases in it has been widely noticed from sustainability point of view. The paper discusses various aspects of Product Life Cycle Simulation based on literature review and results of a project aimed at defining the contents and roadmap for this research area.

Keywords: data management, product life cycle management, simulation, sustainability

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Kannisto, P.
Service-Oriented Business Process Modelling in Operations and Maintenance.
Tampere, Tampere University of Technology, 2011. 88 p. + app. 6 p. (Master of Science thesis).

Abstract: Service-Oriented Architecture (SOA) is a paradigm for modeling the interaction of different parties in a distributed system. In SOA, a high abstraction level leads to platform-independent interoperability. Moreover, different parties are only loosely coupled to each other. As a result of these, SOA is a scalable and inflexible architecture.

As industrial automation systems are typically in inflexible and expensive to install or to modify, it would be beneficial to have all devices interact in the SOA manner. However, current technologies to implement a SOA are problematic from the devices point of view. The technologies require a lot of computational resources, and they also lack support for hard real-time functions. Work has been done to overcome these challenges, but especially hard real-time capable SOA cannot currently be implemented.

Despite their limitations, current SOA technologies can be used for several functions of industrial plants. In this study, service-oriented solutions are created for the estimation of environmental footprints and for condition monitoring. The solutions are modeled as diagrams using a standard graphical notation after which the diagrams are converted to an executable language.

Both implementations show the efficiency of the selected modeling method. The principles of SOA enable the reuse of different resources flexibly in different applications which saves work. A standard structured data format was used in both solutions, and it facilitates integration. As there is a built-in support for the format in modern applications, a solution designer can concentrate on data contents on a high level. Compatibility problems were also encountered, but they were overcome using wrapper services. There were also other integration problems with the technologies used. Despite the problems, graphical modeling saves time compared to textual methods to model communication. It was also recognized that careful design is required in distributed systems to avoid performance problems.

Keywords: industrial SOA, executable business process, life cycle simulation, XML, BPMN, WS-BPEL, Web Services, HTTP, DPWS, real-time system

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Fasoli, T.
Milano, Politecnico di Milano. (Master of Science thesis. In progress).

Fasoli, T., Terzi, S., Jantunen, E., Kortelainen, J., Sääski, J. & Salonen, T.
Challenges in Data Management in Product Life Cycle Engineering.
The proceedings of the 18th CIRP International Conference on Life Cycle Engineering, Braunschweig, 2011. 6 p. (Accepted paper).

Abstract: It is expected that the capability of managing the complete product life cycle in its phases will give the necessary boost for European Manufacturing Industry. Many efforts have been put into the creation of product lifecycle management systems, but it would seem that there is a gap between the existing reality and the specification of expected features. The article addresses this subject from critical point of view and tries to pinpoint the weaknesses of the existing solutions such as standards and database solutions. This work also tries to show the possible ways to follow that could help in solving the problems.

Keywords: product lifecycle management (PLM); product data management (PDM)

Campos, J., Jantunen, E. & Kortelainen, J.
Product Life Cycle Simulation Applying Semantic Data Management.
The proceedings of the 8th International Conference on Product Lifecycle Management, Technische Universiteit Einhoven, The Netherlands, June 11–13, 2011. (Accepted paper).

Abstract: Product Life Cycle Simulation (PLCS) has been given ever more attention as the manufacturers are competing with the quality and life cycle costs of their products. Especially, the need of companies to try to get a strong position in providing services for their products and thus to make themselves less vulnerable to changes in the market has led to high interest in PLCS. A short summary of current status of PLCS is presented especially related to the poor integration of data in Product Life Cycle Management (PLM) systems and in PLCS. The potential of applying semantic data management to solve these problems is thoroughly discussed in the light of recent development. A basic roadmap how the above-described problems could be tackled with open software solutions is presented. Finally, this paper goes through the emerging Web technologies such as the Semantic Web framework and the Web services.

Keyword: Product life cycle, Simulation, Semantic, Data management, Semantic web, Web services

Kannisto, P., Hästbacka, D. & Kuikka, S.
Laitteiden ympäristövaikutusten arviointi palvelukeskeisillä liiketoimintaprosesseilla.
The Automaatio XIX seminar in Helsinki March 15–16, 2011. Tampere, Tampere University of Technology, 2011. 6 p.

Tiivistelmä: Hajautetun järjestelmän mallintaminen palvelukeskeisen arkkitehtuurin (SOA) periaatteita noudattaen tuo monenlaisia etuja. Tyypillisesti palvelukeskeisen tiedonsiirron abstraktiotaso on korkea, jolloin saavutetaan riippumattomuus toteutusalustasta. Toisaalta palvelukeskeinen arkkitehtuuri on skaalautuva. Koska palvelut voivat kutsua toisiaan, jo olemassa olevia palveluita voidaan hyödyntää uusissa palveluissa. Tällöin syntyy kerroksellinen hierarkia, jossa monimutkainen tehtävä täytetään suorittamalla yksinkertaisempia osatehtäviä. Palveluiden väliset kytkennät ovat löyhiä, jolloin konfigurointia tarvitaan vähän: riittää, että tarvittavat palvelut ovat saatavilla ja että niiden osoitteet ovat tiedossa. Tyypillisin tekniikka palvelukeskeisen arkkitehtuurin luomiseen on web-sovelluspalvelut (Web Services), jota käytetään myös tässä työssä.

Palvelukeskeisten liiketoimintaprosessien kuvaamiseen on luotu kaaviotekniikoita kuten intuitiivinen ja ilmaisuvoimainen BPMN (Business Process Modeling Notation). Jotkin ohjelmat osaavat jopa muuntaa graafisesti määriteltyjä liiketoimintaprosesseja koneellisesti suoritettavaan muotoon. Tällöin palveluhierarkioiden koostaminen tapahtuu pitkälti kaavioita piirtämällä.

Internetissä on saatavilla ympäristötietokantoja, joita hyödyntäen voidaan luoda koneellisesti suoritettavia palvelukeskeisiä liiketoimintaprosesseja päätöksenteon tueksi. Niiden avulla voidaan arvioida laitteiden tuottamia saastemääriä niiden elinkaaren aikana resurssien kulutukseen perustuen. Esimerkissä käytettävä tietokanta tukee XML-kieltä, jota käytetään laajasti palvelukeskeisen arkkitehtuurin toteutustekniikoissa. Siten sen integroiminen suoritettaviin liiketoimintaprosesseihin on suoraviivaista. Syntyy hierarkia, jonka pohjalla on tietokannan tarjoama tieto ja sen päällä tietoa käsittelevät liiketoimintaprosessit. Alatason liiketoimintaprosessit suorittavat yksinkertaisia tehtäviä, ja ylemmäs mentäessä suoritetaan yhä monimutkaisempia kokonaisuuksia alempien tasojen liiketoimintaprosesseja käyttämällä.

Työ on esimerkki palvelukeskeisen arkkitehtuurin ja nykyisen web-sovelluspalvelu- sekä XML-tekniikoiden soveltamisesta. Esimerkkitoteutuksella voidaan esimerkiksi vertailla eri laitteiden sähkönkulutuksen aiheuttamaa ympäristökuormaa; tätä tietoa voidaan hyödyntää muun muassa uusia laitteita valittaessa. Palvelukeskeinen arkkitehtuuri on osoittautunut skaalautuvaksi ja joustavaksi lähestymistavaksi. Käytettyihin tekniikoihin liittyy toki haasteita, mutta kokemustemme mukaan niiden selvittäminen ei vaadi ylivoimaisen suurta työmäärää.

Avainsanat: palvelukeskeinen arkkitehtuuri, liiketoimintaprosessit, web-sovelluspalvelut, ympäristö

Hästbacka, D., Kannisto, P. & Kuikka, S.

Business Process Modeling and SOA in Industrial O&M Application Development.
13th International Conference on Enterprise Information Systems (ICEIS), June 8–11, 2011. Tampere, Tampere University of Technology, 2011. 9 p. (Accepted paper).

Abstract: While striving to increase profits in global competition, companies are trying to improve efficiency and reduce costs by outsourcing and focusing on their core functions. For operation of industrial plants this often results in provision of services even for high-priority activities such as maintenance. Integration of external information systems and service providers to business processes and information workflows brings new challenges to application development in order to support introduction of maintenance services as efficiently as possible. This paper discusses the approach of applying business process modeling and service-oriented concepts to development of supporting software applications. Business process modeling is proposed for describing service interactions and information flows, and to function as a foundation for the application development. To satisfy required flexibility in changing business environments, the applications represented as services are composed into executable process workflow orchestrations using standard Internet technologies. To validate the approach a scenario consisting of a condition monitoring process and an environment footprint estimator is presented.

Keywords: BPM, SOA, Application development, Orchestration, Operation and Maintenance, Industry

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4 Conclusions and discussion

One of the main objectives of the Codes project was to gather understanding about the application of computational methods in different engineering disciplines and from different point of views. In the project, the focus was on the one hand in the level of whole product life cycle perspective and, on the other hand, in the details of managing method-specific simulation model data for offline and real-time simulation. The engineering scope of the project was from general life cycle management to process industry system simulation and mechanical engineering finite element method and multibody system dynamics. In addition, the project contained research on applying modern software architectures and development approaches, such as SOA, for product life cycle data management. One of the important topics in the project was the work done on harmonisation of standardisation related to process industry data management and data transfer. This rough description of the project contents give some understanding of the wide spectrum of the focus in the project but also the challenges of the communication and sharing of understanding in the project.

A project with several independent parties, together with relatively long geographical distances, is a challenge for the project administration. This, together with the modern "multitasking" method of running research, i.e. people in project organisation are participating several research projects, industrial assignments, and possibly personal studies, puts high demands on the project management and creating a sharing and co-operative environment for the project. Basic research and basic research -focused applied research have the built-in uncertainty, i.e. some things cannot be known before they have been studied. In addition, the methods and practices selected for the research work have the same burden, i.e. the method or practice planned for some specific task may not be optimal. Due to these natural features of research, the long-lasting and persistent research work and co-operation, careful planning, and continuous roadmap updating process are essential for successful research.

The project model for the Codes research project was to have a wide spectrum of different engineering disciplines involved into on project. The idea was to transfer ideas and concepts between different engineering disciplines and thus increase the learning and ability to innovate. In practice, this showed out to be difficult due to scattered implementation of the research work in time, long distances, and different working cultures. Projects, such as the Codes project, are important for drawing the big picture of the discipline and the subject area, but on the other hand, they may not be optimal for the researchers working in the project. It is difficult to share the understanding of the big lines of the discipline, because they are still forming even though they may have become more visible during the project. The big picture is often forming at the time or after the project is finished, and thus the project cannot provide a channel to share the understanding between the participants. Sharing information and understanding requires fruitful environment for it, i.e. opportunities for natural communication between people from different disciplines have to be provided. In addition, common tasks and joint challenges have to be provided to make the participants to work for a common goal. This is not a trivial task to implement. In Codes project, the research tasks were relatively independent, which did not drive the research work to be interactive and collaborative. On the other hand, the results in many tasks and especially the deliverables were good and the work was efficient.

The role of the non-research organisations that are participating a research project is often somewhat difficult. Depending on the personal characteristics of the participating people, the co-operation between the research parties and the non-research organisations can be fruitful and active. The research parties, as the professionals in doing research, do the actual research work, and the non-research organisations reflect the results to their understanding about the application of the results in their environment. This approach can provide good motivation for both parties and can accelerate the research work. In addition, it can guide the work to more useful directions and further development of the research results to concrete applications. The co-operation is more challenging if the focus of the project is on basic research and the time span for the applications of the results is long. This is especially a challenge for the research parties so that they are able to show the relevance of the work for the participants and thus keep up the motivation to continue the co-operation.

The result and success of the Codes project can be said to be good based on the project deliverables and the understanding of the subject that was gathered during the project. But the most important outcome of the project was the finding that there is definitely room for the further research on the fundamental research topics of this project: *simulation and design tool integration in the product process* and *the management of the simulation-based product life cycle process*.

Appendix A: Project contents

Table 1: The contents of the Codes research project.

#	Task	Description
1	**Management and administration**	
1.1	Project management and administration	Project progress monitoring and administration, meetings.
2	**Applying semantics modelling and standardisation in integration of process simulation and plant design**	
2.1	Application of ISO 15926 in Finnish industry, seminar serie, roadmap and dissemination	Meaning of ISO 15926 standard for designers and end-users. Tools and methods to apply standard in industrial processes. Interfaces to other data representations. Guidelines (roadmap) for Finnish industry.
2.2	Application of ISO 15926 for plant model and simulation model data exchange, demonstration implementation	Demonstration of the application of ISO 15926 classification for information exchange in Simantics platform. Semantic modelling tools for maintaining and extending ISO 15926 classification and for linking it to own classifications.
2.3	Design automation for automation design	Rule-based methods for design automation. Auto generation of control system implementation or simulation implementation from platform independent design formats like automation UML profile.
2.4	Design system and simulation integration through standard solutions.	Use of semantic, ontology-based method and existing plant modelling standards like ISO 15926 for plant design system and simulation integration. Management of complex design data, added intelligence into system integration, rule-based reasoning and mapping framework and validity checking. Auto generating algorithms for dynamic process model from design data. Initial state generating algoritms and methods for a dynamic simulation model.
2.5	PSK and ISO 15926 comparison	Comparison of Finnish national classification standards (PSK) and ISO 15926.
3	**Model-based machine system development**	
3.1	Model-based machine system development process, requirements and challenges	Process description, bindings and relations to other development areas, data and information flow. Pre-study. Three suitable industrial cases described for assuring generality of the developed methods Approach planning resulting detailed work plan Overview of a generalised method – short description of applying to all industrial cases Description on how to iteratively forward details to abstraction levels (in simulation environment and integration to other development environments/tools)
3.2	FEM and CFD tools and development environments	Latest trends with open source software, tools and development environments. Survey and report. Short evaluation of suitable FEM and CFD tools to be linked with industrial development process Review on real-time aspects in industrial test cases
3.3	Managing spatially discretised data in a semantic database	Methods managing spatially discretised model and results data in semantic database How to describe mesh data semantically Use of standard and general formats (STEP, CGNS, UNV, ...) with generic simulation platform How to manage numerical results data How to integrate numerical results data into development environment
3.4	Simulation and development tool integration	Integration of existing open source multibody simulation (MBS), finite element method (FEM) and computational fluid dynamics (CFD) tools and environments with other product development environments. Integration of real-time simulation tools into development environment, application of model-based design process. Most suitable industrial case solved or solution planned to execution ready state

		Generalised method described
3.5	Real-time simulation in model-based development	Real-time simulation applicability for model-based machine system development in industrial use. Off-line model reduction for real-time computing, model exchange process automation, data exchange between real-time simulation environment and off-line simulation, integration to other development process tools. Review on generality of the developed methods Numerical transfer function generation based on off-line model List of potential services and their interfaces
4	**Product life cycle simulation**	
4.1	Product life cycle simulator concept	Pre-study. What PLCS means? How is it constructed, what are the components? What data is needed and how data is managed? What is the added value of PLCS?
4.2	Product reliability and availability in product life cycle simulation, methods and models	Specification and requirement analysis. Description of reliability and availability part of PLCS? What computational methods and models can be used? What are the computational and numerical requirements of this part? What data is needed? What data/information is produced? How this module interacts with other PLCS system?
4.3	Product environmental impact in product life cycle simulation, standards, methods and models (energy and material flow)	Specification and requirement analysis. Description of environmental part of PLCS? What computational methods and models can be used? What are the computational and numerical requirements of this part? What data is needed? What data/information is produced? How this module interacts with other PLCS system?
4.4	Business model impact in product life cycle simulation, methods and models	Specification and requirement analysis. Description of business and organisational part of PLCS? What computational methods and models can be used? What are the computational and numerical requirements of this part? What data is needed? What data/information is produced? How this module interacts with other PLCS system?
4.5	Operation process modelling and management services	Application of process description languages and standards (like WS-BPEL 2.0) for integration of simulation into development process. Overall process modelling (use of BPEL4People and WS-HumanTask). Study of implementation technologies, e.g. SOA and semantics data models.
4.6	Product life cycle simulation platform requirement and technical specification	Requirement specification and technical specification for a demonstration implementation of PLCS, based on Simantics platform.
5	**Dissemination**	
5.1	Project results dissemination	Seminars, workshops, presentations, conferences, project website administration.