THESIS ON MECHANICAL ENGINEERING E67

Synergy Deployment at Early Evaluation of Modularity of the Multi-Agent Production Systems

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Declaration:
Hereby I declare that this doctoral thesis, my original investigation and achievement, submitted for the doctoral degree at Tallinn University of Technology has not been submitted for any academic degree.

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MASINA- JA APARAADIEHITUS E67

Sünergia kaasamine modulaarsuse varaseks hindamiseks mitmeagentsete tootmissüsteemide evitamisel

MARTINŠ SARKANS

TTÜ KIRJASTUS

CONTENTS

ABBREVIATIONS AND SYMBOLS

CAD	-	Computer-Aided Design
CI	-	Commonality Index
COTS	-	Commercial Off-The-Shelf
DAAAM	-	Danube Adria Association for Automation & Manufacturing
DM	-	Data Mining
DSM	-	Dependency Structure Matrix
EAS	-	Enterprise Estonia
GMAW	-	Gas Metal Arc Welding
IMECC	-	Innovative Manufacturing Engineering Systems Competence Centre
JOT	-	Just On Time
MAG	-	Metal Active Gas
MIG	-	Metal Inert Gas
MIM	-	Module Indication Matrix
PCB	-	Printed Circuit Board
PCI	-	Product Line Commonality Index
PD	-	Product Development
PLM	-	Product Lifecycle Management
RF	-	Radio Frequency
RFID	-	Radio Frequency Identification
ROI	-	Return On Investment
SIM	-	Subscriber Identity Module
SME	-	Small and Medium-Sized Enterprises

Symbol	**Unit**	**Description**
C_{co}	-	coefficient of product complexity
d_v^{co}	-	coefficient of the product volume
l_w^{co}	-	coefficient of the welding length
n_{cl}	pcs	number of tool cleaning movements in a program
n_{me}	pcs	number of measurements in a program
n_{mv}	pcs	number of additional movements in a program
n_w	pcs	number of welds in a program
n_{me}^{co}	-	coefficient of the number of measuring
n_w^{co}	-	coefficient of the number of weldments
t_{cl}	s	time for programming tool cleaning movements
t_{me}	s	time for programming one measuring movement
t_{mv}	s	time for programming one additional movement
t_{pr}	s	programming time
t_w	s	time for programming one welding movement
v	mm/s	welding speed
w	m/min	wire speed

INTRODUCTION

Background and problem setting

Nowadays, industry has been moving towards knowledge-intensive processes and products. As products grow more intricate over the time including knowledge from different domains (mechanics, electronics, informatics), they have to be considered as complex systems. Also, the complexity of production processes increases which requires the implementation of complex production systems (e.g. robot welding cells). Therefore, to secure success on the global market the need for suitable methodologies for managing the complexity is increasing.

Nowadays, there is an increasing trend for SMEs to implement production technologies which are more common in mass-production (robots, CNC-machine tools, etc). This enables to increase production efficiency, flexibility and profitability. The implementation and maintenance of such systems poses a great challenge for SMEs because of the lack of resources (human, financial, etc). To implement and introduce this kind of systems in the enterprise right methodologies must be used to achieve the recommended result through the increase of synergy. The term synergy can be considered in the following relationships:

- the quality of products;
- increase in production quantity;
- increase in flexibility;
- increase in synergy in the whole product development process (product-process-knowledge);
- the improvement of complexity management.

During the product development process several modularization methodologies (functional decomposition, modularity indication matrixes, DSM) are in use for a long time. It has a positive impact not only on the development of new products but also on upgrading the existing products. These methodologies support the development of new products and the restructuring of product platforms, but the support for knowledge management for the collected data/info/knowledge is so far not sufficient. Also, the accumulation of the gained knowledge in the enterprise is still poorly supported. To overcome this obstacle data visualization tools can be restructured to represent data in the form of maps, charts, animations or any graphical means that makes the understanding of the content easier for the development team. Graphical representation of data or knowledge has to be empowered to open up the way engineers think about data, reveal the hidden patterns and highlight the connections between system elements. Whereas visualizations seems to be too complex for quick assimilation, tools that create interactive visualizations (mind-mapping, chart drawing, simulations) have to be taken along. They provide users with a number of quick ways to make complex patterns easier to perceive and understand.

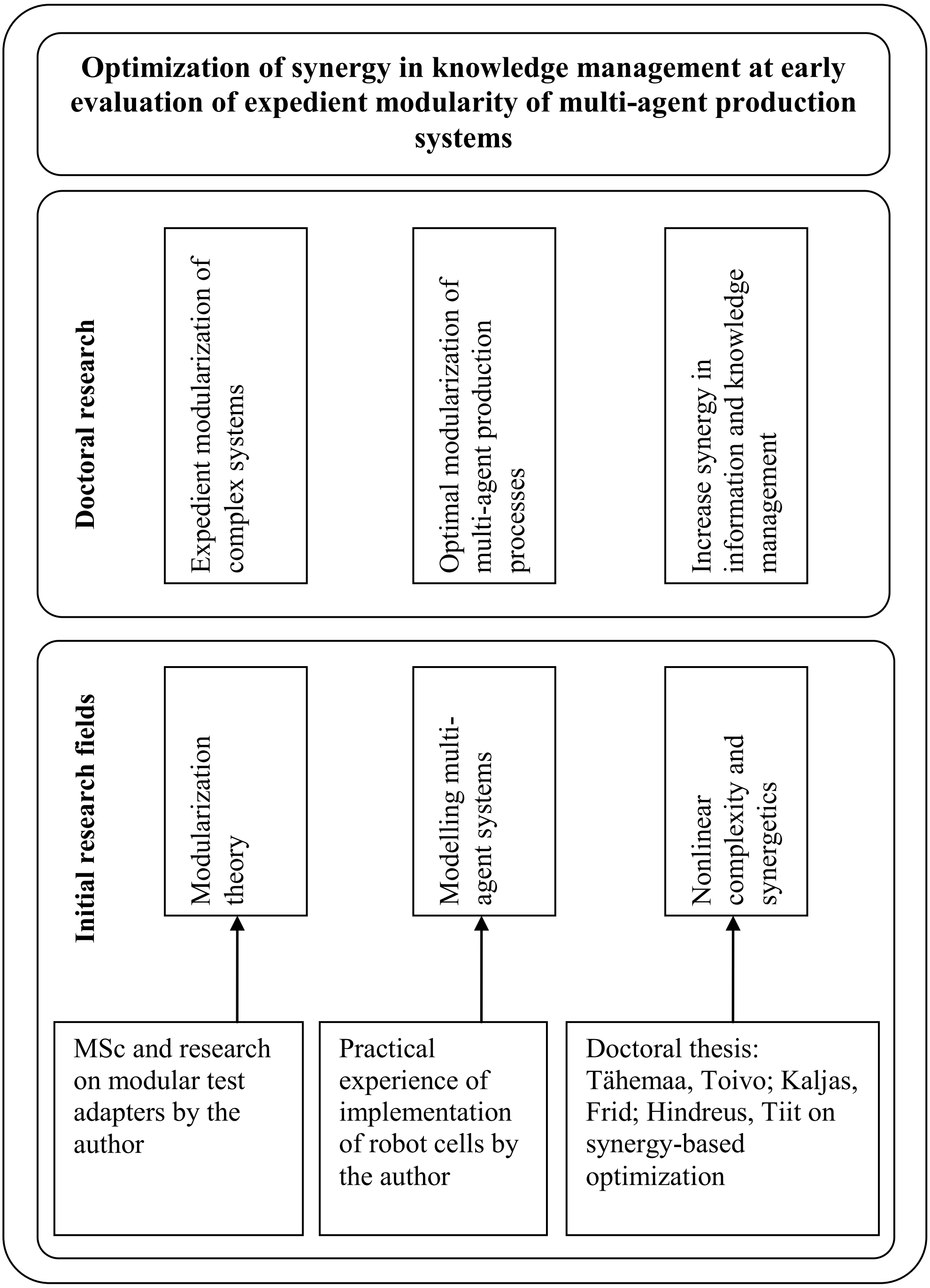

Figure 0.1. Initial research activities leading to doctoral research

Research objective and tasks

The objective of the present doctoral research is to study the possibilities of increasing synergy between knowledge and information visualization at early evaluation of the expedient modularity of intelligent multi-agent production systems.

In this research the next tasks have to be solved:
1. An overview of the research in the field of complex system synthesis and optimization.
2. A feasibility study of the expedient modularization of complex products and production processes.
3. The optimization of the modularization of multi-agent processes at complex production systems implementation.
4. A research into the possibilities for increasing synergy in information and knowledge management in modeling context.

The doctoral research is focused on the following fields: modularization of products, reuse of knowledge, partition of complex systems (modularization, layering) and knowledge management in the conditions of SME.

The methodological basis of the research:
- the theory of matrixes, probability density functions, parallel discreet event modeling
- product decomposition, product integration, the analysis of production processes, complex system integration/decomposition
- synergetics, product modularization, MIM, DSM, a complex nonlinear systems analysis, information and knowledge visualization

The research approach is focused on four levels:
- the product level (modularization, matrixes)
- the production level (modularization of the production cell, layering)
- the knowledge level (info/data/knowledge management for complex systems)
- the synergy level (virtual module, layering methodology)

One approach to the implementation of complex systems of a different characteristic is to select suitable data models, which support the development, implementation and use of such systems in SME. Appropriate data models should be recommended for products analyzed in this thesis.

The reasoning of the present research may be summarized as follows: as the complexity of the product increases, the knowledge spreads through design (methodologies), production (manufacturing technologies), production process (equipment used for production) etc. The effect can be achieved through economy of time by managing the knowledge and connecting different processes (through the accumulation of the knowledge in the company).

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1. OVERVIEW OF THE RESEARCH IN THE FIELD OF COMPLEX SYSTEM SYNTHESIS AND OPTIMIZATION

This chapter includes an introduction to complex systems, main modularization methodologies, the information and knowledge domain and the agents system.

The aim of this research is to establish rules for the selection of product development methodologies depending on the product and production type, and is focused on SMEs. During the design process a great amount of data/knowledge is generated which must be managed in the limited resources of SME. The gathered data/knowledge have to be charted and the information/knowledge management methodologies/rules must be used. The proposal of the framework for the charting of the knowledge is given to enable its use for analyzing the following products and training of the personnel.

It is important to empower the synergetic effect which can be obtained through the modularization/partitioning of products but also through starting the design process earlier by using charted knowledge and reusing the approved modules.

1.1 Essence of complex systems and potentiality of their analysis

All the products included in the research can be considered as complex due to interconnected domains: IT, mechanics, electronics. Under these conditions the design of new products only within one domain (e.g. mechanics) is not possible but the connection between different domains must be considered. This makes it difficult to create new products using traditional design methodologies. As a result, different domains with supporting methodologies must be included. For the design of new products and restructuring the existing ones the suitable methodologies and knowledge reuse must be implemented at the right time.

The systems theory has long been concerned with the study of complex systems, which tend to be high dimensional, non-linear and hard to model. Various informal descriptions for complex systems have been defined, and these may give some insight into their main properties:

- a complex system is one that by design or function or both is difficult to understand and verify, having constant evolution over time;
- a complex system is one in which there are multiple interactions between many different components.
- a complex system is a highly structured system with variations and sensitive to small perturbations.

Simon (Simon, 1996) defines a complex system roughly as one made up by a large number of elements that interact in a non-simple way. According to most definitions interdependence between the elements of a system is seen as an important factor of complexity.

INCOSE (the International Council on Systems Engineering) defines a system as follows: A system is a construct or collection of different elements that together produce results not obtainable by the elements alone. The elements, or parts, can include people, hardware, software, facilities, policies, and documents; that is, all things required to produce systems-level results. The results include system level qualities, properties, characteristics, functions, behavior and performance. The value added by the system as a whole, beyond that contributed independently by the parts, is primarily created by the relationship among the parts; that is, how they are interconnected." (INCOSE, 2010).

The necessity for systems engineering emerged with the rise of complexity in the systems development projects. In this context the complexity incorporates not only engineering systems, but also the logical human organization of data and knowledge. At the same time, a system can become more complex because of the increase in size as well as with a growth in the amount of data, variables, or the number of fields/domains that are involved in the design.

Systems engineering encourages the use of tools and methods to better comprehend and manage complexity in systems. Systems engineering proposes to use methodologies by dividing complex systems into appropriate parts. One of the approaches can be the modularization of the system.

Complex systems consisting of multiple elements with nonlinear interfaces cannot be analyzed without the involvement of synergetics (Haken, 1983). Synergy between systems elements reveals only under the conditions of nonlinear complexity and it opens a way to the meta-level of the optimization of systems structure. This optimization may be supported only by tools of soft computing (integrating fuzzy technology, artificial neural networks and genetic algorithms (Ivancevic & Ivancevic, 2008)

The research team which the author of the present thesis belongs to has a long time experience in developing synergy-based adaptive tools for engineers both for the design of engineering team competence and for quality assurance methodologies (Hindreus et.al, 2010). The research efforts are devoted to fighting against the so-called “bad” engineering (Martin, Kaljas & Reedik, 2006) using the synergy-based approach to empower quality assurance. Talking about synergy and quality relations, it is possible to notice that everything that is done to achieve bigger synergy leads to better quality (Hindreus & Reedik, 2006). Looking into the field of quality assurance, it is possible to set up a hypothesis that the quality of artifacts depends fully on synergy in human activities creating this artifact. Therefore, the synergy-based thinking in systems development is impregnated into all solutions of the present thesis.

1.2 Overview of modularization principles and practices

During the last decades industrial enterprises have become more and more interested in modular systems due to the difficulty to bring higher customer orientation and standardized products together. The **main benefits of the use of modular systems** are lower product costs, less required development time and higher product quality (Meyer & Lehnerd, 1997). Besides, the management of product and process complexity has become an important aspect when utilizing modular systems (Blackenfelt, 2001). Although the use of modular systems in product development leads to a remarkable saving of time and efforts, the development of a modular system itself is still extremely time consuming and complex. Many companies struggle with the modularization of their products without using any scientific approach.

The advantages of modularity are possible economies of scale and scope and economies in parts sourcing (Baldwin & Clark, 2000). Modularity also provides flexibility that enables product variations and technology development without changes to the overall design (Ericsson & Erixon, 1999). The same flexibility allows also for independent development of modules, which is useful in concurrent design or overlapped product development (Roemer, Ahmadi & Wang, 2000) or when buying the modules from a supplier. Modularity also eases the management of complex product architectures and therefore also product development. Modularity can also be used to create product families.

A module is a structurally independent building block of a larger system with well-defined interfaces. A module is fairly loosely connected to the rest of the system allowing an independent development of the module as long as the interconnections at the interfaces are well thought of (Baldwin & Clark, 2000; Ericsson & Erixon, 1999).

Product architecture is a concept for how a company understands their product, e.g. a formal model that explains the partitioning of the product and the relations between different parts. Product architecture should also describe how different product individuals are derived from the product family (unit, function, interface, module, non-module, configuration knowledge, modular product family, PDM). The terms used in this context are the following:

- a unit is a part in product partition;
- a function is a feature of a product wanted by the customer;
- an interface is the way a unit affects exterior (not just geometry, but all inputs and outputs).

When defining a modular platform, the interfaces between the modules should also be defined. For more concrete descriptions the word interface is used for the interaction or connection between two modules. The interface includes the fundamental and often also the incidental interactions between the modules (Pimmler & Eppinger, 1994). Some authors see the interfaces between modules as the core issue of modularity. By designing module interfaces that are stable over the time, robust to variation, simple and defined early in the development process, the development effort may be carried on in parallel, creating variety and derivative products over a time period.

The term "interface" could, in a broader sense, be used for the constraints on the design of subsystems which includes physical attachments points, test points, cooling requirements, mass and moment of inertia, altitude limits, i.e. anything that constrains the design of other subsystems (Reinertsen & Smith, 1992). Interactions, informational and geometrical, may also be classified according to strength; the classes are weak, semi-strong or strong. Interfaces between two modules should preferably be of weak character (Erixon, 1998).

The term **"platform"** comes from the car industry. In the 1920s –and 1930s the major American car companies launched multiple brands to be able to appeal to a more varied public (Tichem, 1997).

There exist many different definitions of **product platforms**:

- a platform is the physical implementation of a technical design that serves as the base architecture for a series of derivative products (Baldwin & Clark, 2000);
- the platform … is a collection of common elements, especially the underlying core technology, implemented across a range of products (Erixon, 1998);
- a product platform is the foundation for a number of related products, typically a product line. While all products are unique in some way, they are related by the common characteristics of the product platform (Duffy, Smith & Duffy, 1998);
- a platform is a relatively large set of products' components that are physically connected as a stable sub-assembly and is common to different final models (Meyer & Lehnerd, 1997).

The product platform is a set of subsystems and interfaces that form a common structure from which a stream of derivative products can be efficiently developed and produced (Meyer & Lehnerd, 1997). As the technological foundation of product families, a platform is the physical implementation of a technical design that serves as the base architecture for a series of derivative products. The platform also embraces manufacturing technology and process employed in production (Meyer & Lehnerd, 1997). The definition of the product platform can be broadened from physical parts to the next four dimensions: components, processes, knowledge, people and relations. A product family (also known as product portfolio) is a set of variants of a product to fulfill a certain set of customer needs.

When implementing a product platform the issue of the **reuse of approved modules** is an important issue. It enables to reduce the design time of new products, increase the quality of the solutions and increase the efficiency of the product platform. Reuse means that something (properties, solutions, etc) repeats itself in a product, and in different variants and models of a product. This something can be:

- complete building units, i.e. function and assembly modules;
- groups of parts, i.e. part modules;
- solutions, i.e. scale modules;
- design elements;
- a user interface.

Design reuse can now be considered as an activity "to reflect the utilization of any knowledge gained from a design activity and not just past designs and artifacts" (Duffy, Smith & Duffy, 1998). The concept of re-using can be seen as inherent within the natural process of design. Sreeram and Chawdry (1998) claim that, due to the potential for use of well tested and optimized concepts and objects, engineering design reuse can be utilized to fulfill the requirements of decreasing design times, increasing design quality, improvements in the predictability of designs and reduced costs.

In summary, for most complex systems decomposition decisions strongly influence the need for coordination, and the knowledge of remaining interactions between sub-systems gives an insight into where and how to coordinate. As the decomposition of a system into rather independent sub-systems minimizes and simplifies coordination effort, it is a powerful tool in the reuse strategy (Thompson, 1967).

There is a general tendency to divide complex systems into smaller parts so that the development process gets more visible and manageable. One of the approaches in this context is to use modularization. To make all the gathered knowledge perceptible to the designer, the usage of suitable visualization methodologies is needed. To fulfill all these requirements in order to get a clear idea of the dynamic structure of the product and production processes, it seems appropriate to use the DSM technology.

The **Dependency Structure Matrix** (further as **DSM**) technology was developed by Steward (Steward, 1981). Due to its outstanding capability of describing the interactions of a system's components, the use of the matrix methods has become more and more popular (Erixon, 1998; Pimmler & Eppinger, 1994; Suh, 1990; Clarkson, 2001). Dependency matrix-based methodologies are advantageous for modeling many types of systems, networks and processes. Their utility in these applications stems from their ability to represent the complex relationships between the components of a system in a compact, visual, and analytically advantageous format.

A DSM is a square matrix with identical row and column labels. The matrix shows the interaction of each element, highlighting complex relationships between components, teams and activities. The differences in DSM-based applications are given in Figure 1.1.

A component-based DSM documents interaction between elements in complex systems architecture. This type of the DSM provides us with the knowledge about taxonomy which helps differentiate the strength of these interactions. After developing taxonomy for interactions, an optional quantification scheme helps weigh them relative to each other. Pimmler and Eppinger provide an example of how such a scheme might be approached (Pimmler & Eppinger, 1994). In this case off-diagonal square marks in the DSM are replaced by a number - here, an integer - 2, -1, 0, 1, or 2. In the design process negative synergy seems to be excluded as the aim is to attain maximal positive synergy (Hindreus, 2009). Coordination complexity can be significantly reduced if the elements are clustered or modularized so that their interactions occur predominantly within subsystems rather than between them (Baldwin & Clark, 2000; Rechtin, 1991; Sanchez & Mahoney, 1997). In synergy-based design the DSM seems to be a valuable tool in the details' domain to empower modularization.

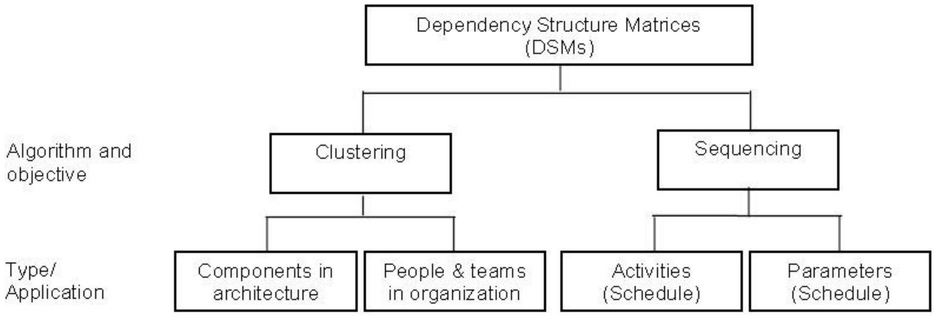


Figure 1.1. Classification of DSM types (Browning, 1998)

A team-based DSM reflects the information flowing between individuals and teams and this approach seems to support people in the configuration of robot welding cells.

The optimization approach to an activity-based DSM consists in ensuring that the right information is available at the right place at the right time; activities are properly sequenced, relevant constraints and requirements are given as quickly as possible; and mistakes are minimized. Finally, it must be decided which activities in an iterative procedure to begin first. In the present research it is a suitable tool for the development of production processes. The sequencing of parameters may have some use in modularization practice.

The DSM method is a technique that can be applied to many problems to analyze the underlying design puzzle, and give both mathematical and deep practical understanding. The DSM enables to divide and manage complex systems. The proposed seeming advantages of this methodology are described below:

- it enables to order the design activities (and other connected activities) or the need for competency on the time basis;
- it is possible to evaluate the strengths of the interfaces or activities (strong, weak, weight) which connects them in a more tight or a more dispersed way;
- through the optimization of the DSM indexes activities and modules/groups are formed which include previous restrictions;
- it divides tasks into groups/modules;
- it is suitable for large projects/products and for big corporations;

1.3 Synthesis of robot systems taking account of information treatment

The implementation of industrial robots has been an increasing trend in the world during the last decade. The implementation of robots exceeded the number of 100,000 installations per year in 2004 and the trend is increasing. During the year 2012 the estimation of robot installations is about 1,057,000 units worldwide (Litzenberger, 2009).

The majority of tasks done with robots are repetitive and do not change during a long period of time, but the development of robot technological possibilities has been rapid. The robots were introduced also in areas where the implementation was considered not profitable or impossible before (construction industry, logistics operations).

Robots have been applied for a long period mainly in mass production. To stay competitive in the world market the manufacturing of cost efficient and client-based products is also important for SMEs and we can see fastening implementation of robots in this sphere of production. Applying robots and manipulators for producing small batches and a great variety of products is the main direction of development. The availability, competitive prices and plain programming made it possible and feasible. In the three-dimensional virtual robot environment the "on-line" and "off-line" programming is more process-oriented and enables operators to implement products faster.

The implementation of robots in small and medium-sized production has special features. In addition to short cycle-times, which are prerequisite when producing small batches, the rapid setup and introduction of new products have significance in this case too.

For example, the introduction of robot welding cells in SMEs is a difficult task because of the complexity of the system and quite often the lack of competencies and lack of the appropriate methodology in companies. To be faster the complex system must be divided into smaller and simpler parts using a modular approach. This approach gives an integral overview of the system and makes the tuning precise and effective to each system/process part individually.

A lot of authors have analyzed robot implementation by using different scope. Their approaches include several subjects and focus on concrete areas like welding, calibration, programming etc. The areas covered:

- general trends in the world (field of use, robotization volume) (Litzenberger, 2009);
- programming of robots (programming systems, optimizing programs, off-line programming) (Gonzalez-Galvan, et.al. 2008);
- coordination, calibration (using cameras and sensors) (Dolinsky, Jenkinson & Colquhoun, 2007);
- welding processes (MIG/MAG, laser+MIG, quality assurance) (Kim, Son & Yarlagadda, 2003);
- scheduling of operations, workload (Zachaaria & Aspragathos, 2005);

- criteria for robot selection, modeling system, (modular architecture, product family) (Bhangale, Agrawal & Saha, 2004);
- kinematics and singularity (Horin & Shoham, 2006);
- production process (reuse of process knowledge, cycle time, bottlenecks) (Gultekin, Karasan & Akturk, 2009);
- monitoring, controlling of the system (Bruccoleri, 2007)

So, an extensive study has been carried out to assess the suitability of robots-for SMEs. Although these articles do not cover all the aspects of the implementation of the whole complexity of the system, they can be used for the sub-division of application tasks. A fundamental research was done on developing robots suitable for SMEs under the European 6th Framework called "SMErobot" (SMErobot, 2010).

To better describe complex systems, it is feasible to introduce the concept of agents. **Agents** can help to define the interconnections between the different parts of the system.

As a concept the agent has existed already for thousands of years. The Oxford American Dictionary gives two meanings for the word "agent":

- "a person or thing that takes an active role or produces a specified effect". The connotation is that agents are active entities that exist in the world and cause it to change;
- "a person who acts on behalf of another, for example, managing business, financial, or contractual matters, or provides a service".

Computer science researchers have used the word "agent" for more than 25 years with a range of different meanings. They define an agent as "an entity that performs a specific activity in an environment of which it is aware and that can respond to changes" (Sterling & Taveter, 2009). There is an associated metaphor of an agent as a representative that suggests several qualities (Sterling & Taveter, 2009):

- being purposeful in both senses of agents (existence in the world, ability to change external conditions);
- controlled autonomy, or the ability to pursue its own goals seemingly independently;
- the agent needs to be situated – that is, aware of the environment around it. It must be capable of perceiving changes and responding appropriately.

Agents can also be seen as entities that enact roles – it can act the environment, perceive events, and reason.

A system may be treated as a set of entities or components connected together to make a complex entity or perform a complex function. If all connected entities are agents, we have a **multiagent system**.

In the present research the treated products (an adapter, a luminary light source, smart dust, a robot welding cell) can be considered as complex systems and also as multi-agent systems.

It can be presumed that the implementation of every multiagent system follows a systems development life cycle and next stages which can be described as:

- a stage of gathering requirements;
- an analysis of the requirements. The analysis goes hand in hand with design, where trade-offs are expected to allow the building of a system that meets users' requirements;
- system implementation, testing, and maintenance.

Adopting the agent metaphor in the case of developing complex systems raises both the visibility and abstraction level of interactions between agents. Therefore, the modeling of systems with multiple agents, both human and manmade, interacting with a diverse collection of hardware and software in a complex environment is a really complicated task. The term "sociotechnical systems" has sometimes been used to indicate such systems. A sociotechnical system has been defined as one that includes hardware and software; has defined operational processes; and offers an interface, implemented in software, to human users (Sterling & Taveter, 2009).

In the present research it is necessary to select a suitable approach for complex system decomposition (and also the system implementation). One possible way is to divide the system into layers by using related domains (e.g. product technology, a production system). As the layers can include different information and knowledge, it is feasible to use its modularization. Modularization enables the formation of different modules (product, process, program) which makes the system more manageable. In this case agents can be introduced to increase system flexibility.

1.4 Synergy aspects of information and knowledge management

Considering this research it is necessary to define the concept of "synergy" used in the present context. According to Oxford Dictionary the word "synergy" or "synergism" refers to the integration or cooperation of two or more drugs, agents, organizations, etc. to produce a new or enhanced effect compared to their separate effects. So there must be "something" that makes integration successful and it is called (positive) synergy. However, sometimes we are also witnesses to unfortunate integration and it is called "asynergy" (negative synergy). (Hindreus et.al, 2010). However, synergy also has a qualitative side, where changing the input parameters of the system results in dramatic changes in the system's behavior. The reason for such changes is allocating the system to order or enslaving parameters that can be interpreted as the amplitudes of the macroscopic patterns at the self-organization of microscopic ones (Haken, 2004).

The synergy-based approach has been used successfully in physics, chemistry, sociology, medicine, business and also in engineering (Mikhailov & Calenbuhr, 2002). Despite the wide existence of synergy effects in nature and artifacts, the real deployment of synergy in engineering is often hidden behind the terms of optimization, rationalization, effectiveness, self-development etc.

It is obvious that synergy problems cannot be treated with scientific methods of reductionism as they reveal themselves only in complexity of nonlinear dynamics and may be followed by tools of computational intelligence (soft computing) integrating fuzzy technology, artificial neural networks and genetic algorithms (Ivancevic & Ivancevic, 2008). The key to synergy is optimization in its wider interpretation including its logical, mathematical and physical basis. So such a type of optimization may be aimed at attaining the maximum synergy level for safety-critical products like space and nuclear technology. However, for non-safety-critical products the optimization of the synergy level is market-driven and closely related to the moral ageing and wearing of the products (Hindreus et. al, 2010). In the present doctoral research it is necessary to focus on the achievement of synergy in a sociotechnical multiagent system. It means that it is necessary to find possibilities to compensate weak sides and amplify the common useful abilities of both technical means and human behavior.

The fundamental bibliographic research on synergy in information and knowledge visualization is given in the book by Tergan and Keller (2005). Using this as a guide and using a number of other sources, the basis of the statement was compiled serving as the platform for the present research, but first it is necessary to explain how main notions are understood and used in the context of the present thesis.

Data are raw being symbols or non- interpreted facts without any relation to other data. Data simply exists in any form, usable or not and does not have meaning beyond its existence (Tergan & Keller, 2005).

Information is data that has got meaning through its interpretation of them in pragmatic context and relational connection. It is important that information is the same only for those people who attribute to it the same meaning. From there data that has been given meaning by somebody and, hence, has become information, may still be data for others who do not comprehend its meaning (Tergan & Keller, 2005). Information may be distinguished according to its features, origin, status of cognitive manipulation. There we can distinguish “facts”, “opinions”, “objective information”, “subjective information”, “primary information”, “secondary information”. Also, information can be distinguished according to its representational format.

Knowledge is information, which has been cognitively processed and integrated into an existing human knowledge structure. The most important difference between information and knowledge is that information is outside the brain and knowledge is inside (Tergan & Keller, 2005). Knowledge may be owned by a person, a group of persons, or by society. Knowledge is dynamic and its structure is constantly being changed and adapted to the affordances in coping with task situations. The key problem in researching synergy in teamwork is the management of useful knowledge, which forms the basis of competence.

By cognitive accessibility knowledge may be explicit or tacit. Explicit knowledge can be expressed either symbolically, e.g. in words or numbers, or pictorially, and can be shared in the form of scientific formulas, product specifications, visualizations, manuals, universal principles, and so forth (Edvinsson & Malone, 1997). Explicit knowledge can be readily transmitted among individuals, formally and systematically.

Tacit knowledge is highly personal and therefore hard to formalize, making it difficult to communicate or share with others. It consists of beliefs, perceptions, ideals, values, emotions, and mental models and is deeply rooted in an individual's action and experience (Edvinsson & Malone, 1997).

Recently, it has been suggested that knowledge may not be restricted to "know-what" and "know-how" but has to be supplemented with "know-where" (Siemens, 2005). This notion of know-where is tantamount to the notion of resource knowledge, the knowledge of where to find information, which may be used as a knowledge resource (Tergan & Keller, 2005).

Visualizations of information and knowledge play an important role as visualizations capitalize on several characteristic features of the human cognitive processing system. According to (Ware, 2005), the "power of a visualization comes from the fact that it is possible to have a far more complex concept structure represented externally in a visual display than can be held in visual and verbal working memories". In this regard, visualizations are cognitive tools aiming at supporting the cognitive system of the user. Visualizations can make use of the automatically human process of pattern finding (Ware, 2004). They can draw both on the visual and the spatial working memory system (Baddeley, 1998; Logie, 1995). It is suggested that using multiple codes involves cognitive processing in different subsystems of the human working memory and therefore supports processes of learning (Mayer, 2001). Visualizations can enhance our processing ability by visualizing abstract relationships between visualized elements and may serve as a basis for externalized cognition (Scaife & Rogers, 1996; Cox, 1999).

The idea of **information visualization** is referred to in a variety of contexts of meaning. In general, psychologists use the term to signify a representational mode (as opposed to verbal descriptions of subject-matter content) used to illustrate in a visual-spatial manner, for example, objects, dynamic systems, events, processes, and procedures. In practice information visualization is used in the context of processing, comprehension, and retention of information in static, animated, dynamic, and interactive graphics (Plötzner & Lowe, 2004).

However, computer scientists define the term in a more narrow sense and referred to it as "the use of computer-supported, interactive, visual representation of abstract non-physically based data to amplify cognition" (Card, Mackinlay & Shneidermann, 1999). So in computer science, information visualization tends to be a specific technology. According to Carr (1999), information visualization of abstract data is of particular importance for information retrieval if the underlying data set is very large (e.g. in the case of searching for information in the World Wide Web) and the goals of the user with regard to information retrieval are not easily quantifiable.

For **knowledge visualization** the spatial strategies are required to help individuals in acquiring, storing, restructuring, communicating and utilizing knowledge and knowledge resources, as well as overcoming capacity limitations of individual working memory (Holley & Dansereau, 1984). Jonassen (1991) has described a variety of visualization methods for fostering spatial learning strategies and technologies used for the visualization of knowledge. The most often used methods are mind mapping and concept mapping methods. Mind maps were suggested as a spatial strategy that uses only key words and images to aid personnel in structuring ideas and taking notes (Buzan, 1995). In order to cope effectively with complex cognitive task requirements, techniques for the external representation of individual knowledge in a visual-spatial format are suggested to facilitate "the coherent representation of new information in semantic memory" (Holley & Dansereau, 1984) and to acquire and convey structural knowledge. Visual external representations of knowledge are often processed more effectively than propositional ones because they "support a large number of perceptual inferences, which are extremely easy to humans" (Larkin & Simon, 1987).

According to Dansereau (2005), the concept of "knowledge visualization" in a strict sense is restricted to externalizing aspects of knowledge by the individual herself or himself in a "freestyle mapping mode". In literature, the term "knowledge visualization" is, however, also used if a knowledge structure of an expert is presented to students as a means for self-assessing knowledge and for aiding comprehension and navigation.

In the **present thesis** the attention is focused on introducing the synergy approach to interpreting information and knowledge visualization addressed to the fields of expedient modularization in the design of multi-agent production processes and product modularization in order to build a knowledge-base for technical education.

It seems that in the present context it is better to use the term "knowledge visualization" with a focus on structure visualizations for the representation of conceptual knowledge. It is possible to assert that from a representational perspective knowledge visualization and information visualization have one feature in common: they aim at visualizing structures.

During building up the research platform it is clear that both research domains – information visualization and knowledge visualization – have reached high technological standards and offer a variety of useful applications in different working, learning, and problem solving scenarios.

Anyway, it is a reality that the development of a rational system of information and knowledge transfer under the conditions of limited resources and personnel typical of SMEs is a critical task the aim of which is to achieve the effectivity of complex sociotechnical systems.

1.5 Conclusion of Chapter 1

1. All objects of the present research – modular products and robot systems – belong to the category of complex nonlinear systems. From this side it makes their analysis more complicated as it is necessary to use soft computing tools. However, from another side it opens up a way to use high level synergy-based optimization that is possible only in a nonlinear world.

2. The most suitable theoretical basis for the analysis of complex nonlinear systems seems to be the DSM technology, which makes it possible to visualize all interactions between system elements and to schedule the design activities so that adaptive system design tools based on team competence could be used.

3. Rational Product Lifecycle Management (PLM), with the involvement of product platforms, families and redesign, is impossible without the suitable modularization of products and also production processes. Hence, it is through the enhancement of interconnections between modules and layered systems architecture that is possible to solve the evergreen problem in which phase of development to start modularization.

4. As modern production systems are a complicated mix of information technology, intelligent production equipment and operators the multi-agent intelligent system philosophy seems to be a suitable meta-approach for the optimization of such systems.

5. The key to the optimization of complex nonlinear systems is the empowerment of the synergy in information and knowledge management allowing to achieve economic solutions of classical automatization technology also under the conditions of SME.

2. FEASIBILITY STUDY OF THE EXPEDIENT MODULARIZATION OF COMPLEX SYSTEMS

2.1 Background to modularization research

Nowadays, in addition to the particular challenge of a quick response to dynamic customer needs, manufacturing industry is facing wide variations and increasing complexity of products along with rapidly changing design and production technologies. Research in operational management suggests that firms can mitigate the negative impact of product variety on operational performance by deliberately pursuing modularity in the design of product family architectures and platforms. In an effort to better respond to heterogeneous customer needs, many firms find it appropriate to increase product variety offered to customers. Although the use of modular systems in product development leads to remarkable savings in time and effort, the development of a modular system is seen as a difficult task when dealing with complex systems.

The development of product families built on product platforms and shared modules has been the subject of intensive research efforts. Meyer & Lehnerd (1997) have analyzed extensive case studies on platforms, pointing out their advantages and challenges, and demonstrating their ability to save costs. Other researchers (Sanderson & Uzumeri 1995) and (Henderson & Clark 1990) have also shown that the use of platforms has given companies an edge on the number of products they can offer and on their profitability over their competitors. Such a decision also tends to present the firm with a number of challenges with respect to the performance of its operations. In fact, as product variety increases, a firm would experience lower performance of its internal operations because of higher direct manufacturing costs, manufacturing overhead, delivery times and inventory levels.

Modularization is an engineering approach, which organizes and structures complex products, processes or systems into a set of sub-systems, which can be developed and assembled independently of the final product. The modular design approach tries to define standardized modules, which can be used to create variation of products. Modularity is often discussed in terms of having the ability to create product variants by altering some modules in the final product variant or by having a modular system (platform), which allows a combinatorial assembly of the final product variant. The goal of component sharing is to strive for high variety in the marketplace and low variety in the plant (Stake, 2000).

2.2 Research base and used methodologies

For the research three different products were selected based on their differences (needed production quantity, product complexity) and the need for modularization:

- a luminary light source (Fig 2.1) is a mass product for lighting purposes where wide variations are required;
- smart dust (Fig 2.2) is used as a tool for distance measuring of the parameters (vibration, humidity, noise level) of the production equipment;
- a test adapter (Fig 2.3) is used for functional and electrical testing of mobile phones.

Glamox HE Ltd is a leading supplier of lighting solutions to the professional building market. They offer a range of lighting brands where luminary light sources form a large share. Luminary light sources are highly client oriented and therefore a wide variation of product design variants are needed. Managing such a large number of products is a complicated task for the company. The number of current parts in a product platform has to be reduced. The problem is how to limit the number of different parts for the company and assure large variability of the products for the customer. To decrease the complexity in production similar or reusable modules must be defined.

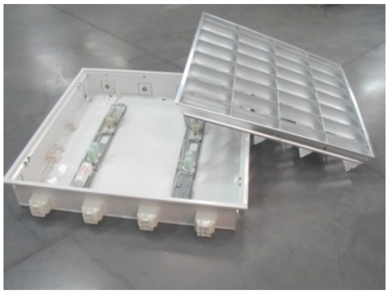


Figure 2.1. Exhibit of a luminary light source (cover opened)

Distributed computing solutions based on miniature computing devices called ”smart dust” are used as sensors which are integrated into small-sized boards and equipped with accumulators. They can be used for industrial applications for gathering different types of data (temperature, humidity, noise etc.). Small dimensions allow deployments deeply embedded into the environment and the relatively low price makes deployments with a high number of nodes feasible. A modularized and reconfigurable sensors network model was built at the Tallinn University of Technology (Preden, Sarkans & Otto, 2007).

For industrial application the product to be created should be modular and re-configurable. The creation of new products with rapid prototyping must be quick depending on the area of use. Also, a housing for the mote based on these requirements should be designed. Creating and updating of the product based on modular architecture should make the overall development process faster.

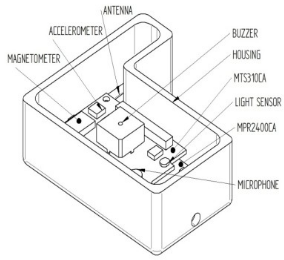


Figure 2.2. CAD model of a housing for smart dust (cover not shown)

The aim of this research was to introduce smart dust based monitoring methodology to be used for searching for possible fault conditions and logging them into the database for a further analysis or predictive maintenance. The mote based monitoring systems are more than just alternatives for eliminating cabling - they provide on-site signal conditioning, thereby reducing the processing required on a central monitoring node if such exists. It is suitable for factory conditions where equipment is distributed all-over the factory. Therefore, cooperation possibilities with different companies are considered.

The research on a test adapter for mobile phones was connected to a company called JOT Eesti Ltd, producing test equipment for electronic industries, particularly test adapters for mobile phones. A test adapter consists of special functional units which serve as an interface between the tested phone and the measuring device. Previously, an adapter was designed and produced individually for each testable phone model. The product development process was time consuming and constrained. The inexpedient number of designed and produced adapters forced to seek ways to reduce the number of different adapters and increase the number of reusable modules.

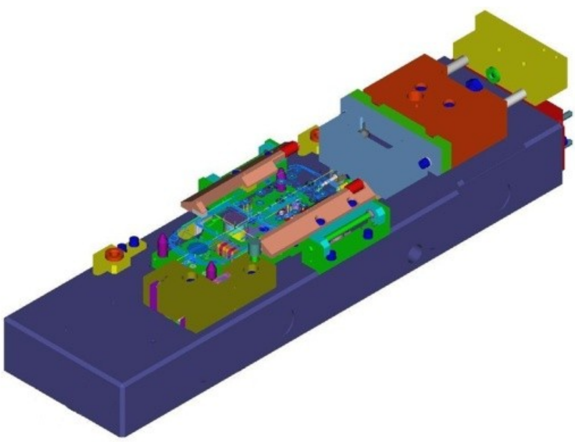


Figure 2.3. Test adapter for mobile phones

The test adapter is a product-specific equipment and the need for a suitable platform increases due to the wide variety of mobile phones. Module reuse is considered appropriate in product platform architecture to step up the product development of new test adapters.

The methodologies used in the research on the three different products for modularization and the expected outcomes are shown in Table 2.1. For each product different methodologies were used depending on the complexity of the product. Also, different outcomes are shown based on the complexity of the product and the need for a detail level configuration by the companies.

Table 2.1. Methodologies used for modularization and the expected outcomes

Methodology used/outcomes	**Luminary light source**	**Smart dust**	**Test adapter**
Functional decomposition	x	x	x
MIM (Module Indication Matrix)	x	-	x
DSM (Dependency Structural Matrix)	-	-	x
Interface type definition	x	x	x
Interface strength definition	x	-	x
Platform architecture schematics	x	x	x
Module reuse possibilities	x	x	x

2.3 Modularization of luminary light sources

The creation of a product platform was started from analyzing functional structures of all luminary light sources produced in the company. After the comparison of functional structures, the common and unique functional units were determined and a modular product platform was developed according to production requirements. Product architecture must be created on the basis of possible modules - it will help the creation of new products and the configuration of the ready ones. Architecture must also reflect client specific solutions. Besides "hard" drivers, for example technology push and carry over, the impact of "soft" drivers, such as styling, common unit and recycling, were also investigated. Styling has especially high driver values for consumer products. Using MIM, the functional units were analyzed and conclusive module drivers were set. Recommendations for the development of luminary light source modules were formulated.

To create a common platform, the next steps should be followed: functional decomposition of luminary light sources, composition of modules using MIM and creation of a common modular product architecture. Based on overlapping functions, an analysis of technical solutions can be made using MIM to find common modules.

By **functional decomposition** of a light source it can be divided into smaller blocks – units. Some of the outsourced blocks (the capacitor, the ballast, the starter, the lamp, etc.) are considered as black boxes. Functional decomposition of the electrical part is shown in Figure 2.4 (Sarkans & Roosimölder, 2004). Mechanical units are: body, body caps, holders, gear tray, reflector, reflector's holders, starter holder, lamp holder, transformer, condenser, stickers and wires. The analysis is mainly focused on the units that are produced in the company. Interactions between units were determined according to the type and strength. The details of the decomposition process are described in (Sarkans & Roosimölder, 2004).

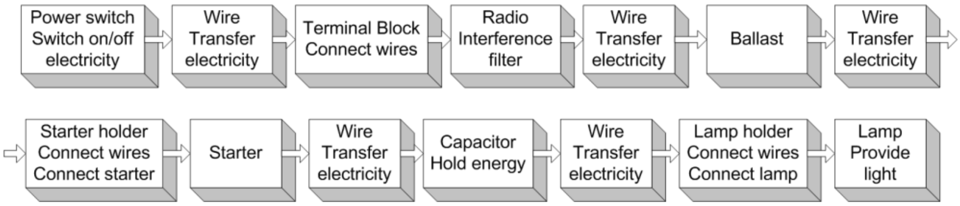


Figure 2.4. Functional decomposition of the electrical part

Potential modules were determined using MIM, which helped to define which technical solutions (units) are suitable as independent modules and which modules can be outsourced. The module driver "carry over" has a high score, which indicates that almost all technical solutions could be used during new product design. The module driver "strategic supplier" helps to find which modules should be outsourced and to decide which module's development is the core competence of the company. The soft module driver "styling" refers to the modules which should be designed in the company.

Module Drivers / Technical Solutions	Carry Over	Technology Push	Planned Design Changes	Different Specification	Styling	Common Unit	Process/Organization	Separate Testing	Strategic Supplier	Service/Maintenance	Upgrading	Recycling	
Body	9		6		9	9	3					3	39
Capacitor	6								9	3	3		21
End cap	6								9	3	3		21
Gear tray	3				6	3	3						15
Louvre	9				9	6						3	27
Frame (Reflector)	9		6		9	6						3	33
Ballast	6	6	6						9				27
Lamp holder	6								9	3	3		21
Starter holder	6								9	3			18
Starter	6								9	3			18
Radio interference filter	6								9				15
Terminal Block	6						3			3			12
	78	6	18	0	33	24	9	0	63	18	9	9	

Figure 2.5. MIM for luminary light sources (scale: neutral 0, weak 3, moderate 6, strong 9)

Luminary light sources have slot type modularity which refers to a system where each type of module is connected in a certain position by a standard interface. The analysis shows that all the listed technical solutions in MIM have strong enough drivers to be defined as modules (see Fig 2.5).

After defining the modules derived from technical solutions, a modular product architecture can be established. All 747 solutions of the production scale of luminary light sources are included. It gives an overview of the product family and helps the creation of new light sources. Modularized product architecture indicates module types and relations between modules and the base module as well. The platform architecture (see Fig 2.6) simplifies the selection, allows suitable modules to be combined and varied during the design of new light sources. The set of approved modules will reduce design time, but some unique modules should still be designed.

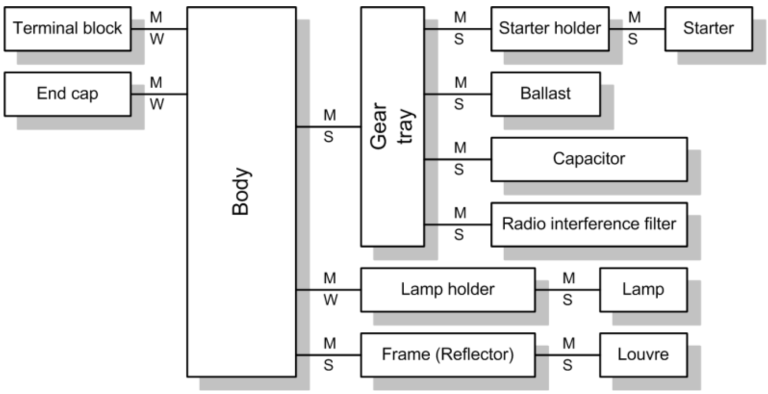


Figure 2.6. Modular platform for a luminary light source and interactions between the modules (interaction types: M – mechanical, I – informational and E – electrical)

As a result of the present analysis the following recommendations to the company were given. Considering the remarkable overlap of functions, the functional decomposition of luminary light sources should be applied only to products of the product family. With the help of MIM the company's core competence modules and modules for outsourcing could be identified more simply. To receive cost-efficient solutions all technical and strategic relations should be considered. Accordingly, further research is needed using the DSM approach. The modular product platform simplifies the design and manufacturing process of luminary light sources. Product platform modularization in the design of luminary lights will reduce the number of different modules and will make it possible to reuse the modules in new models. The designed modules for luminary light sources could be easily updated in regular time cycles and swapped to gain added functionality. The platform architecture could help in finding the best solution in cooperation with the customer.

2.4 Defining the modular product platform and the design of a housing for smart dust

Industrial monitoring systems based on wireless sensors are becoming a reality (Kevan, 2006; Krishnamurthy, 2005). In non-critical applications cheap COTS (Commercial off-the-shelf) hardware can be used for industrial monitoring, offering relatively cheap and reasonably accurate monitoring information. Wireless sensor nodes, also called smart dust or motes, are offered commercially by many companies, such as Crossbow, Dust Networks, Sensinode, Gumstix to name a few. A smart dust mote typically contains a processor, memory, a set of sensors, a wireless communication interface and an autonomous power supply. A small form factor combined with these features enables new opportunities that are not available using conventional computing platforms.

The modularized test network model was also built at the Tallinn University of Technology (Preden, Sarkans & Otto, 2007) for adding information input from a flexible manufacturing system consisting of two robots, CNC mill, two CMM and a conveyor system. The system was monitored by eight motes. Data from sensor boards was analyzed and saved in the database

The functions of all motes were analyzed to find out the common set of functions for a basic smart dust product with the aim to build up a modularized smart dust platform. Such a platform will consist of common modules and unique modules, which will be needed for creating new smart dust product configurations. It will lead to the reuse of common modules. Interactions between modules were determined according to the type (see Fig. 2.7).

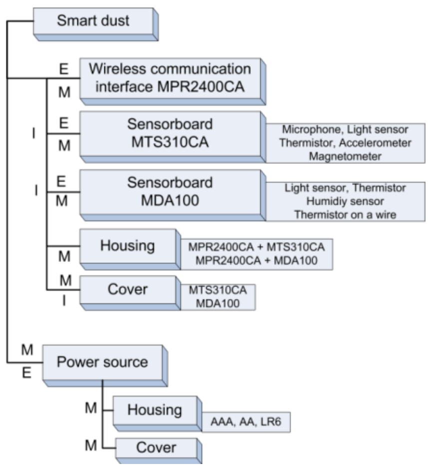


Figure 2.7. Modular platform for smart dust and interactions between the modules. (interaction types: M – mechanical, I – informational and E – electrical)

Modular architecture contains one-to-one mapping from functional elements to details and defines different interfaces between details. The main function of the product is connected with product detail functions and physical properties, which is defined as product function structure. The functional structure of casing for an electronic device is described in the (Matsi, Sarkans, Otto & Roosimölder, 2007).

Based on modular structure each functional element is placed into an independent module which includes strictly defined interfaces with other modules, enabling to make changes in the module without affecting other modules. Such an approach is also suitable for the apparatus industry where the variety of functions in an electronic device can lead to the need for changes. The modules can be created and developed independently from other systems and the configuration is faster.

Based on modularization information the suitable housing for the product was created. The circuit boards are fitted inside the housing (see Fig. 2.2). The cover for the sensors depends on the configuration of the sensors and is changeable. The power source has its own housing. The size of this housing depends on the power cells used. The modular structure enables the changing of different modules without affecting others. It means that the power source can be changed for different elements when needed.

The mote based monitoring systems are more than just alternatives for eliminating cabling - they provide on-site signal conditioning, thereby reducing the processing required on a central monitoring node if such exists. A mote can provide an estimate on the monitored physical phenomena, instead of only providing a sensor reading converted from the analogue format to the digital one which would have to be interpreted in order to obtain an estimate on the state of the physical phenomena. Simple data interpretation algorithms can be used on the motes themselves, thereby reducing the amount of data that needs to be communicated from each mote to a central processing or logging node. Given enough information and decision making privileges, a mote can even decide if the phenomena it is monitoring are within the allowed bounds and the mote can adjust its operation based on that decision.

The novelty of this research is the new application area for "smart dust" using it in the industrial environment and sensor data gathering for workcenter maintenance purposes.

2.5 Modularization of the test adapter

The tester with an adapter enables fully automatic tests of mechanical, RF, electrical, audio and visual interfaces of the cellular phones in a repeatable and reliable environment in order to maximize product quality and capacity with minimal labor costs. The creation of a product platform for test adapters by reusing modules is discussed in this chapter. Not all modules could be reused for the development of new products; the appropriate ones should be selected. The methodology for this should be suggested. 36 test adapters which share a common product platform were under investigation. Functions and parameters for the required modules must be defined. All the existing modules must be evaluated by using modularity matrixes to find out the appropriate ones.

As a result, an updated product platform for test adapters has to be created using fewer original modules. This approach should reduce the development time and production costs when creating new test adapters.

36 different types of test adapters were created at the company (JOT Eesti Ltd) in the course of time. Some designs from the existing solutions were reused during the development of new adapters. A set of solutions that could be applied as modules were chosen. However, the set of test adapters was not generalized and the advantages of product modularization were not perceived enough until the problem became economically obligatory. As a result, a workgroup was assembled to carry out the modularization of test adapters and to initiate the modular platform thinking in the company. The "platform thinking" as a new way to create adapters was introduced in the enterprise. This way of thinking was both economic and customer oriented. The purpose was to achieve lead time shortening, higher efficiency in production and quicker model changes. This, in its turn, enables increased sales and lower costs.

Great effort was required to implement the modular platform strategy for the first time as the intensity of the effort being much higher than in case of a common adapter design process. The objective is, though, that it will pay off in the development of consecutive models. Modular platform based products make it possible to outsource the manufacturing and autonomous testing of modules, which will lead to better quality. The results of the study will be used in an adapter platform development program, where the target is to increase the reliability of new adapters and lower production adaptation time by standardizing features and creating a solutions verification program, thus minimizing the design work needed for the design of new adapters.

The main and support functions common to test adapters and mobile phones were specified as follows:

The main functions: pushing the power key, pushing the volume key, contacting with the SIM (Subscriber Identity Module), contacting with the battery, contacting with the system connector etc.

Support functions: pushing the system connector, pushing the main test block, connecting the main PCB (Printed Circuit Board), ODUMAC® fastening etc. Support functions are functions with the help of which the modules are pushed into the working position.

Based on these functions, the modules were decomposed as follows: the BC (Bottom Connector) module, the MTB (Main Test Block) module, the SIM probes module, power & volume key pusher modules, the battery contact plates module, left & right locker modules, the microphone module etc.

In this process the functions of all test adapters were analyzed to find out the common set of functions for a basic adapter platform. On this base a possibility was found to build up a **modularized adapter platform**. Such a platform will consist of common modules and unique modules, which will be needed for creating new adapters. It will lead to the reuse of common modules.

Adapters have slot type modularity, which refers to a system where each type of module is connected in a certain position by a standard interface. Adapters have a base, where modules are fitted to create a new adapter. Modules have strong mechanical interaction with the base. Changing the module will change the base configuration. The main PCB and test probes have weak electrical and informational interaction. The PCB change should not change the interface.

A functional scheme was composed and a possible modular adapter architecture was created. The modules were defined by the performed functions. On the basis of interactions the interfaces between the modules were specified. The final architecture of the modularized adapter platform was determined on the basis of the created modules and interfaces (see Fig 2.8).

Modularized platform architecture shows module types and relations between the modules and the base module. The platform architecture simplifies selection, allows combining of suitable modules and varying them during the creation of a new adapter.

After the evaluation some existing modules proved unnecessary and they were eliminated from use. As a result, 16 modules were suggested, from which 4 could be integrated as the main test block module. In this stage of development the **reuse of modules** crops up.

Experience has shown that on average the assembly operation time for parts is about 10 seconds (T_{norm}) and that average final assembly operation between modules varies between 10 and 50 seconds, $T_{norm} \leq T_{int} \geq 5\ T_{norm}$.

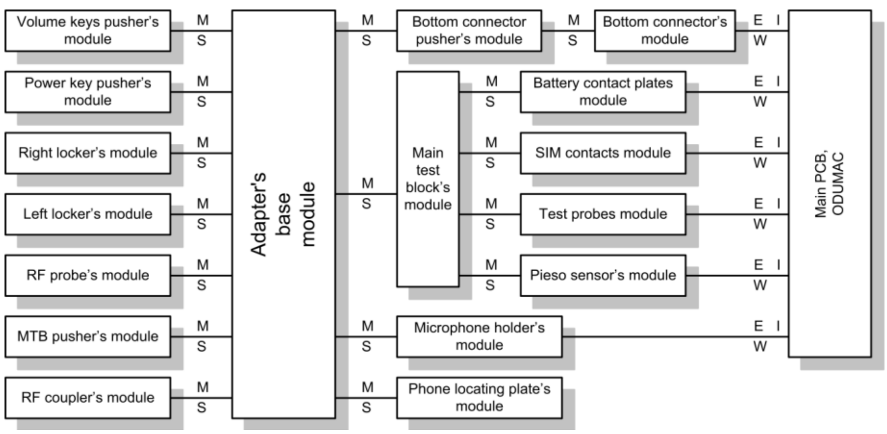


Figure 2.8. Architecture of a modularized adapter platform and interactions between the modules (interaction types: M – mechanical, E – electrical, I – informative. Interaction strengths: W – weak, SS – semi-strong, S – strong)

If the average final assembly time (interface) is equal to the average assembly time for parts, the ideal number of modules can be found. (Erixon, 1998) suggests using a graph where the ideal/minimum values are plotted as the number of parts in products and the relation between internal assembly (T_{int}) and part assembly (T_{norm}) times. This graph can be used to estimate the targeted number of modules for the division of the product into modules. When $T_{int}/T_{norm} = 1$ and the count of different parts in complete products is 120 (as in our case), the suggested ideal number of different modules is 12.

Also, the number of functions and maintenance issues were taken into account. The ideal number of different modules could be seen as appropriate (valid) if the assembly duration of modules is about 10 seconds per interface. The number of modules used in 36 different adapters before and after modularization is shown in Figure 2.9 We can see a significant reduction in the number of modules. Additional information can be found in an article by (Sarkans & Roosimölder, 2004).

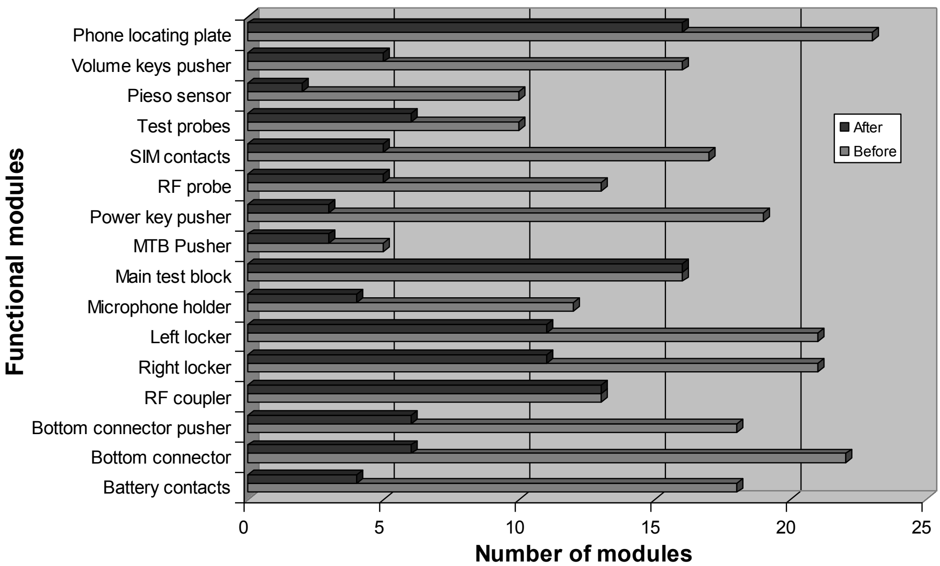


Figure 2.9. Number of modules used in 36 different adapters before and after modularization

In addition, the number of modules was determined with the help of the **Module Indication Matrix** (MIM) (see Fig 2.10). As we can see 16 modules have strong enough module drives but four of them could be integrated together. As a result, the final number of modules should be 12.

After all the modules were gathered together, a database had to be created. At the same time a knowledge base had to be created that would bind the modules into a unified database together with the information about them. This information has to be accessible for designers, clients, project managers, sales representatives and other related persons.

Module driver / Functional unit	Carry Over	Technology Push	Planned Design Changes	Different Specification	Styling	Common Unit	Process/Organization	Separate Testing	Strategic Supplier	Service/Maintenance	Upgrading	Recycling	Σ points per function
Volume keys pusher	❾		❸			❻		❸		❸			24
Pieso sensor	❾					❾				❸			21
Test probes	❾		❻	❸		❻		❻		❻			36
SIM contacts	❾					❻		❻		❾		❻	36
RF-Probe	❻		❸	❸		❸	❻			❻			27
Power key pusher	❾		❸			❻		❸		❸			24
MTB pusher	❾			❸		❾				❸			24
Main test block						❻		❸		❻		❻	21
Microphone holder	❻					❻		❻		❸			21
Left Locker	❻		❻	❸		❻				❸			24
Right Locker	❻		❻	❸		❻				❸			24
RF coupler	❻		❻	❻		❸		❻		❻			33
Bottom connector pusher	❾			❸		❾				❸			24
Battery contacts	❾					❻		❾		❾		❻	39
Bottom connector	❻					❾		❾		❾		❻	39
Phone locating plate	❸		❾			❸				❻	❻		27
Σ per module driver	111	0	42	24	0	99	6	51	0	81	6	24	

Figure 2.10. MIM for the test adapter (scale: neutral 0, weak 3, moderate 6, strong 9)

For this purpose, the **ADB (Adapter Design Book)** was introduced in the company to decrease the dilemma of comparatively "static" nature of modular systems. It is often quite difficult or impossible to make changes in modular systems requiring a wide redesign. In order to reduce the number of necessary redesign, interface design that is stable over time and robust to variation is a crucial part of modularization projects. The interfaces should be designed with potential for future needs. Another possibility could be the use of strategies that support the design of "dynamic" modular systems. Such strategies should help to minimize the efforts for redesigning that are necessary to fulfill the changed or extended requirements.

ADB is an interactive database situated in the company server. All the approved modules with connected knowledge are described, which makes this model more flexible to use. Also, a 3D model of the adapter's "blank design" is introduced to the designers. It can be used as a starting point when designing a new adapter. This approach enables to reduce the design time from 8 weeks to 4 weeks.

2.6 DSM and the expedient modularization principle

During the process of test adapter modularization the DSM technology was used. Figure 2.11 shows the DSM for the Main Test Block (MTB) of the test adapter. This DSM was used mainly to specify the sequence of the design process. As the MTB is a crucial part of the adapter, proper design and faultless operation are required. During the development of the MTB a mechanical designer, an electrical designer and a RF designer are involved. Consequently, it is necessary to coordinate their activities.

As one can see, the DSM gives a good overview of the MTB structure combined with design activities. The DSM opens a possibility to increase the synergy relations in design activities (see Fig. 2.11). This is the key to achieve better synergy in teamwork.

Parallel to the modularization of luminary light sources, which is described in part 2.3 of the present thesis, an analysis of the design and quality assurance process was provided. Integrating the DSM technology and the Design Domains Theory, a synergy-based design methodology was proposed, which is connected to the competence of the design team (Kaljas, 2005). Later, the methodology was enlarged to the whole product quality assurance system (Hindreus, 2009). As a result, 4 DSM were formed in the design process for market analysis and transformation, organs and part domains. In addition, for the quality assurance process, a DSM was formed for product development preparation, design resources management and product realization and analysis. These researches are interpreted in the present thesis through the domain of common organs and described in part 2.3.

In all of these DSM the modularization of activities is prescribed, which is the basis for the expedient modularization concept. Expedient modularization starts from the very beginning of product development or market analysis. Therefore, modularization does not have only a "hard" context but also a "soft" one. On the principle of expedient modularization, in Chapters 3 and 4 of the present thesis a virtual modularization principle is developed which is suitable for multi-agent systems, thus also for intelligent production systems.

PARTITIONED DSM		SIM contacting	SIM base	SIM moving	Battery contacting	Battery base	Battery moving	Testpad contacting	Testpad base	Testpad moving	Vibro contacting	Vibro base	Vibro moving	RF contacting	RF base	RF moving	PCB fastening to base	PCB for electrical components	PCB for connecting MTB comp	PCB for connectors	SIM electrical connection	Battery electrical connection	Testpad electrical connection	Vibro electrical connection	RF electrical connection	MTB base	MTB Pusher fastening MTB	MTB Pusher moving MYB	MTB Pusher Base	MTB moving	MTB fasetening components
		1	2	3	5	6	7	9	10	11	13	14	15	17	18	19	27	28	29	30	4	8	12	16	20	23	24	25	26	22	21
SIM contacting	1	1	1	1																											
SIM base	2	1	2	1																											
SIM moving	3	1		3																											
Battery contacting	5				5	1	1																								
Battery base	6				1	6	1																								
Battery moving	7				1		7																								
Testpad contacting	9							9	1	1																					
Testpad base	10							1	10	1																					
Testpad moving	11							1		11																					
Vibro contacting	13										13	1	1																		
Vibro base	14										1	14	1																		
Vibro moving	15										1		15																		
RF contacting	17													17	1	1															
RF base	18													1	18	1															
RF moving	19													1		19															
PCB fastening to base	27																27	1	1	1											
PCB for electrical components	28																1	28	1	1											
PCB for connecting MTB comp	29																	1	29	1											
PCB for connectors	30																		1	30											
SIM electrical connection	4	1		1															1		4										
Battery electrical connection	8				1		1												1			8									
Testpad electrical connection	12							1		1									1				12								
Vibro electrical connection	16										1		1						1					16							
RF electrical connection	20													1		1			1						20						
MTB base	23																								1	23					
MTB Pusher fastening MTB	24																									1	24	1	1		
MTB Pusher moving MYB	25																											25	1		
MTB Pusher Base	26																										1	1	26		
MTB moving	22																									1				22	
MTB fasetening components	21		1			1			1			1			1											1				1	21

Figure 2.11. DSM for the Main Test Block (MTB) of the test adapter, where synergy relations are expressed on a 3-step scale: 0 – indifferent (blank), 1 – moderate, 2 – strong

2.7 Conclusion of Chapter 2

1. Dividing products into modules and defining platforms enables the designers to better comprehend/manage the overall system and reuse the approved solutions when designing new products. However, there is no adequate support for gathering respective knowledge and possibility to visualize it.

2. To overcome the lack of knowledge visualization, it is recommended to compile an Adapter Design Book (ADB) for the enterprise to describe the test adapter product platform where the recommended modules are also included with the engineering knowledge they carry.

3. Depending on the nature of the products, the descriptions of the platforms of interdisciplinary products differ inevitably from each-other. The more complex the system is, the more intricate interactions will be formed inside the platform. The methodologies used for modularization must be more on a detail-level when product complexity increases.

4. As the charting of the knowledge during the modularization process is limited, there is a need to take into use the more advanced knowledge management systems (knowledge visualization, databases) to increase synergy. Using support from knowledge management and visualization, it is possible to start modularization earlier in the product development process where the approved design solutions can be reused.

5. For attaining a better synergy in the development process, the principle of expedient modularization is recommended to use where the design activities are also modularized, enabling to start modularization from the very beginning of product development. The described approach seems to be applicable also in multi-agent systems.

3. OPTIMIZATION OF THE MODULARIZATION OF MULTI-AGENT PRODUCTION PROCESSES IN SMEs

3.1 Special features of automation under SME conditions

SMEs can achieve a great competitivity advantage by implementing a welding robot cell. However, introducing robot welding cells in SMEs is a difficult task because of the complexity of the system and quite often the lack of competencies and lack of the appropriate methodology in small companies. To be smarter the complex system should be divided into smaller and simpler parts using a modular approach. This approach gives an integral overview of the system and makes the tuning precise and effective to each system/process part individually.

The present research is based on the implementation experience of three different systems. These case studies were made in typical SMEs:

- A robot-welding cell for mini-loaders (further as case Norcar). Used for the welding of mini- loaders base-frames, tools and lifting beams.
- A robot-welding cell for cylinders (further as case Norrhydro). Used for the welding of cylinder tubes and cylinder rods.
- A robot-welding cell for a bed frame (further as case Stram). Used for the welding of bed base frame components.

These systems are treated in this study as complex systems. The main properties of the systems are summarized in Table 3.1.

Table 3.1. Robot-welding cells and system properties

Process characteristics	**Case Norcar**	**Case Norrhydro**	**Case Stram**
Product technology features	Over 40 products, different requirements	Over 40 products, similar requirements	Product family, similar requirements
Production system	Big and complex system, flexible	Big system, flexible	Small system, less flexibility
Software support	RobotStudio, CAD, Rapid, Omron	RobotStudio, CAD, Rapid, Omron	RobotStudio, CAD, Rapid, Logo!
Installation mode	Additional set-up in the factory	Additional set-up in the factory	Additional set-up in the factory
Jigs properties	New products, additional jig	New products, jig upgrade	New products, new jig
Programming features	Many movements, sophisticated programs	Little movements, sophisticated programs	Many movements, simple program
Welding process features	Complex welding process and parameters	Special requirements for the process	Mild requirements for the process

3.2 Divided intelligence through the modularization of the control networks and knowledge layering

By splitting the robot welding implementation process into smaller and better manageable actions, the introduction of complex systems will get more feasible for SMEs. Due to the complexity of the systems the next main problems have to be solved:

- integration of the system with the real factory;
- implementing production technology for robot production;
- development of jigs;
- economic and ROI (Return of Investments) calculations.

Complex system decomposition is possible by using different approaches. One option is to divide the system into layers by using related domains (for example product technology, production systems, jig development). As the layers include different information and knowledge, it is feasible to use modularization. Modularization enables formation of different modules (product, process, program), which makes the system more manageable. As a result, the problem of expedient modularization crops up once more. To form interconnections between different system layers simultaneously, two approaches can be applied:

- modularization and modules share information between modules in different layers;
- involvement of agents to share information and decisions between layers and their agents.

For example:

- product module information can be shared for the formation of the program module;
- the agent in the product analyzing layer can share information to the next layer or make a decision about the product feasibility for the robot welding cell;
- each level of the system includes different implementation process part(s), and it is possible to move between different layers and fill them in with different information and connections.

In this research the term "module" is used as a physical (product) or virtual (program) module. For the definition of modules different approaches can be used (the MIM matrix, functional decomposition, the DSM etc.). The module is used for simplifying the description of the system (by dividing system parts into manageable/appropriate parts/subassemblies). By dividing the complex system with the help of expedient modularization, a shorter implementation process can be achieved.

Implementation refers to actions from system selection and technology description to the introduction of the real product. During the implementation process software agents are introduced, which enable communication (links) between the different parts of the system and the modules.

Methodologies suitable for the decomposition of complex robot cells are the following:
- the domain-based approach (product, production process, production technology, production equipment);
- modularization approaches (modularization of the product, defining technological modules, defining program modules);
- knowledge visualization for charting the scenery of domains.

The expected synergy increase is expected in the following activities:
- calculation of programming time;
- estimation of product suitability for the robot cell;
- the graph of implementation efficiency (breaking point between full production ability and the volume of programming activities);
- division of products into groups based on programming time and the load of the robot welding cell.

So, it is possible to achieve the objective through expedient modularization at the implementation of the robot cell, where each system is described using domain-based layers and modules. At the same time the knowledge obtained from the previous implementation process should be used for the start up of new robot welding cells.

3.3 Practical contributions to the formation of robot welding cells

3.3.1 Case study of Norcar

The robot welding cell in Norcar BSB Eesti Ltd is shown in Fig. 3.1. and its configuration is given in Table 3.2. The product portfolio for welding includes more than 40 products. The MIG welding process is used for product assembly and 20 different welding parameters are used depending on material thickness and the dimension of weldment. The robot welding cell is defined considering the great flexibility for the implementation of new products in a short period of time and so the selection methodology for the suitable product for this welding cell is defined.

For the selection of system (robot welding cell) components, first an analysis of products was done to choose the appropriate ones and to chart their welding technology. Based on maximum dimensions and the mass of the products, the selection of positioners for the robot welding cell was made. The selected positioners are ABB IRBP 750 A (two axis positioner) and ABB IRBP 750 L (one axis positioner) with the maximum handling capacity of 750 kg and with the repetitive accuracy of ±0,05 mm. To maximize the active exploit time of the robot two workpiece positioners were selected. To increase the robot's work envelope and reachability in different positions, an additional axis was added to the system (linear track ABB RTT 2400 L) with the travelling length of 2700 mm and the positioning accuracy of ±0,05 mm. The selected robot for the system is ABB IRB 2400L with the positioning repeatability of ±0,06 mm.

Based on the analysis of welding technology and the selected parameters, the welding equipment Esab MigRob 500 was selected, which enables MIG/MAG welding, and the allowed maximum welding current is 500 A. This ensures the welding of thick (15 mm) materials when welding parameters are high (voltage 29 V, current 250 A). This configuration of the robot welding cell guarantees the expected flexibility when introducing new products and when the additional development of the cell is needed. One idea during the system selection was to use flexible manufacturing. Based on this idea, the cell was introduced with roller-tables, where the product can be automatically fed to the robot work zone.

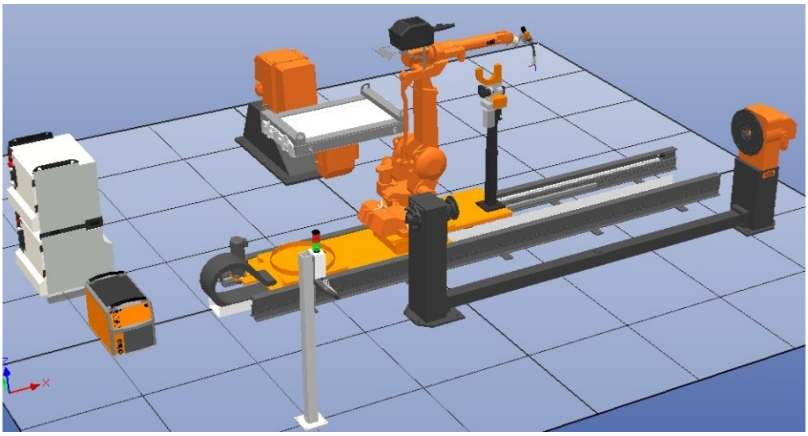


Figure 3.1. Robot welding cell 3D configuration in Norcar BSB Eesti Ltd

Table 3.2. Norcar robot cell configuration

Equipment	**Model**
Welding robot	ABB IRB 2400L
Controller	ABB IRC5 Teach Pendant, software Robot Ware 5.12
Linear track	ABB RTT 2400 L
Positioner 1	ABB IRBP 750 A
Positioner 2	ABB IRBP 750 L
Welding source	ESAB MigRob® 500
Security features	Sick® light curtains

Before the purchase of system elements, the whole system was simulated in the ABB RobotStudio 3D computer software environment. After the purchase the components (robot, positioners, track, welding equipment, roller-tables, welding jigs and security equipment) were assembled and their functionality were tested. In Finland Norcar factory all the components were linked together and tuned. Welding parameters were selected and robot programs were made for two of the products (adapter, lifting beam). In Norcar BSB Eesti Ltd the implementation process of the robot welding cell continued. Additional products were introduced, welding parameters were tested and implemented and operators were trained.

Based on the Norcar robot welding cell, extensive information was gathered about products and production. The analysis of this data gives us a possibility to introduce the implementation chart of the system (based on welding/programming time ratio), group the products (based on production quantity/production time). This analysis is shown in detail in chapter 3.4.

3.3.2 Case study of Norrhydro

The robot welding cell in Norrhydro OY is shown in Fig. 3.2 and its configuration in Table 3.3. A system was designed for the welding of cylinder rods. The welding process depends on the rod and the loop diameters. The double-pulsed MIG welding process was used for product assembly. 40 different welding parameters were used depending on material thickness and the dimension of weldment.

During the development of this robot welding cell the knowledge obtained from Norcar system implementation was used. Process description was complicated requiring complicated robot work movements to obtain good welding results. During the implementation, problems arose as the knowledge about the welding process was insufficient. Also, additional programming help was needed for correct implementation.

The need for the system arose during the growth of the market for hydraulic cylinders. As high requirements for welding were expected, the welding power source was selected in cooperation with the specialists of the factory. It is Selco Genesis 352 PSR with MIG/MAG process capabilities and the possibility to use double-pulsed welding. Due to the increase in production quantity the decision of process automation was accepted.

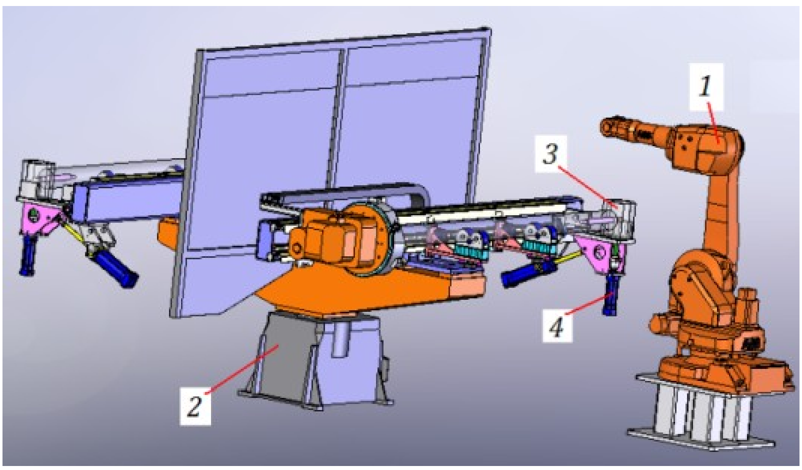


Figure 3.2. Robot welding cell 3D configuration in Norrhydro OY

Table 3.3. Norrhydro OY robot cell configuration

Equipment	**Model**
Welding robot	ABB IRB 1600
Controller	ABB IRC5 Teach Pendant, software Robot Ware 5.12
Positioner 1	ABB IRBP 500C, modified for cylinder production
Welding source	Selco® Genesis 352 PSR
Security features	Sick® light curtains

The components of the system were selected based on the biggest product (dimensions, weight). As the welding process is concentrated into a certain work zone, a robot with a fixed stand was selected (ABB IRB 1600). The positioner was redesigned for the welding of cylinder-rods (ABB IRBP 500C). The welding jig was designed and assembled by a subcontractor. The whole system was assembled in Norcar Finland factory. The testing and tuning was also done in Norcar.

The system was installed in the course of two weeks. Also, the training of operators was provided during the implementation and several programs for different products were created. The system needed additional improvement on-site because some issues were not considered during the design of the robot welding cell. As the manual welding movement during the process is very complicated (including knots and arcs), the regular robot wave-movement cannot be used during the welding process. The necessary movements needed to be programmed by hand using robot Teach Pendant.

3.3.3 Case study of STRAM

The robot welding cell in Stram Ltd is shown in Fig. 3.3 and its configuration is given in Table 3.4. The system was designed for one concrete product (the VIP bed frame) but the possibility for expansion was to be considered. The flexibility of the system was increased by implementing an intelligent fixture. This created a good interface between the bed frame and the fixture, which enabled to replace products quickly. The MIG welding process was used for product assembly and 4 different welding parameters were used depending on material thickness and the dimension of weldment. The system throughput was planned for great productivity (30,000 bed frames/year) but in the SME conditions. The main purpose of implementing this robot welding cell was to decrease the production time of the bed frame VIP. Using hand welding, the production time was 40 minutes. After implementing the robot welding cell, the production time decreased and finally reached 10 minutes/product.

During the development of this robot welding cell the knowledge obtained from Norcar system implementation was used. At the system implementation the layered approach and some modularization principles were used (product modules, production program modules).

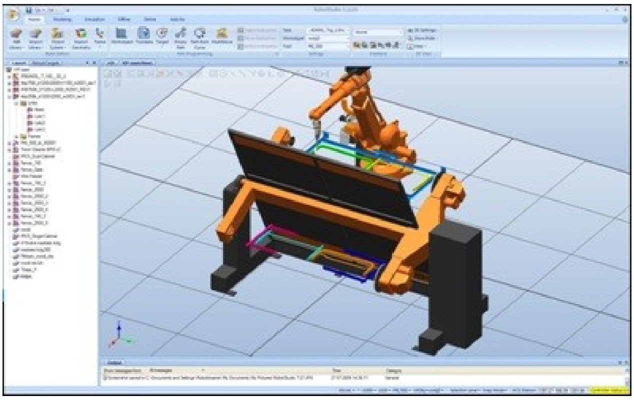


Figure 3.3. Robot welding cell 3D configuration in STRAM Ltd

Table 3.4. Stram Ltd robot cell configuration.

Equipment	**Model**
Welding robot	ABB IRB 2400L
Controller	ABB IRC5 Teach Pendant, software Robot Ware 5.12
Positioner 1	ABB IRBP 250K
Welding source	ESAB AristoMig® 5000i
Security features	Sick® light curtains

To introduce the robot welding cell in Stram Ltd, first a technology analysis of the product was done. For the selection of the robot welding cell equipment production volume was the main parameter. Based on this, welding time, welding technology and possible solutions were determined. Three different concepts of the robot welding cell were introduced in the company. By weighing different parameters (price, flexibility, cycle time), one system from the solutions was selected. Before the purchase of the system elements, the whole system was simulated in the ABB RobotStudio 3D computer software environment. During this simulation the product, jig, the robot and the positioner were analyzed, reachability was tested and cycle time was calculated.

After the ordering of the system from ABB, the design of the welding jig was finished. To increase the flexibility of the whole system, the welding jig was designed as intelligent. It consists of fastening cylinders, sensors and a controller. Flexibility increases due to the interface between the robot-controller and the welding jig controller.

The robot welding cell was assembled and tested first at the Norcar BSB Eesti factory. The installation of the system and the operators were trained in the course of one week. In the first weeks the system worked with the cycle time of 15 minutes/product. During months the system was fine-tuned (welding parameters, welding positions, production optimizing) and the cycle time was reduced to 10 minutes/product.

During the implementation the domain-based approach was used for different stages of the project. It was shown that this kind of approach reduces the development time of the whole system. The graph about the implementation (welding/programming ratio) is shown in Chapter 3.4.

3.4 Outcomes for the implementation of robot welding in SMEs

In this part the following necessary developed tools for speeding up the robot implementation for robot welding are presented:

- equations for the calculation of programming time
- implementation chart (welding vs programming)
- grouping of products
- the DSM of the implementation process

All the system level outcomes are concentrated in Chapter 4.

3.4.1 Estimation of programming time

One of the most important parameters when using robot welding is the estimation of **programming time**. When production batches are small and changing rapidly, the estimation of programming time is necessary to attain the advantages of robot-welding in the conditions of SMEs. This approach is applicable to products where single-pass welds are used, gas metal arc welding (GMAW) is suitable and the robot is programmed on-line using teach-pendant. The data and knowledge gathered from the implementation of the 3 different welding robot cells were used here as a basis. These cells were implemented in the conditions of SMEs and the product base was selected to exceed 10 products for each robot.

It turns out that not all the parameters have the same importance when estimating programming time. The most important parameters are: the overall length of welds in the product, the number of welds of the product, the number of measurements in the program and the volume of the product. However, it is also necessary to include the following factors: the number of movements between welds and the number of tool cleaning movements. When dividing the programming process into smaller parts, the accuracy of the final result can be increased significantly. The next durations of programming operations must be defined. Although the exact values are difficult to define, because they vary between products and programs, the estimated programming time limits can be used in Equation 1.

$$t_{pr} = (t_w * n_w + t_{me} * n_{me} + t_{mv} * n_{mv} + t_{cl} * n_{cl}) * C_{co} \qquad (1)$$

where:
t_w – time for programming one welding movement, (180 s to 240 s);
n_w – number of welds in the program, pcs;
t_{me} – time for programming one measuring movement, (120 s to 180 s);
n_{me} – number of measurements in the program, pcs;
t_{mv} – time for programming one additional movement, (60 s to 120 s);
n_{mv} – number of additional movements in the program, pcs;
t_{cl} – time for programming tool cleaning movements, (120 s to 180 s);
n_{cl} – number of tool cleaning movements in the program, pcs;
C_{co} – coefficient of product complexity.

Table 3.5. Table for the selection of parameters for the calculation of the coefficient of product complexity on programming time

		Complexity				
Symbol	Unit	Simple	Ordinary	Complex	Very complex	Comparable weight
n_{me}	pcs	1…5	6…15	16…30	31…50	35%
l_w	m	0,1…1	1,1…5	5,1…10	10,1…30	25%
d_v	m^3	0,1…0,4	0,5…0,9	1…1,49	1,5…2	10%
n_w	pcs	1…5	6…20	21…50	51…100	30%
C_{co}		1	2	3	4	

The **coefficient of product complexity C_{co}** is used in this equation because the products differ from each-other considering their configuration and technology (see Table 3.5). The coefficient is based on the gathered data from the case studies. It is first recommendation and can be updated with the data used by the different enterprises.

The equation for the calculation of the coefficient of product complexity C_{co} is given below:

$$C_{co} = 0{,}35 * n_{me}^{co} + 0{,}25 * l_w^{co} + 0{,}10 * d_v^{co} + 0{,}30 * n_w^{co} \quad (2)$$

where:
C_{co} – coefficient of complexity;
n_{me}^{co}- coefficient of the number of measurings (weight 0,35);
l_w^{co}- coefficient of welding length (weight 0,25);
d_v^{co}- coefficient of product volume (weight 0,10);
n_w^{co}- coefficient of the number of weldments (weight 0,30).

The increase of the volume of the product does not influence the complexity as much as the increase of measurements in the program.

For the **estimation of product suitability** for production for robot welding cells in the conditions of SMEs it is important to define the following parameters: programming time, welding time, production quantity and program running time.

Based on this information it is possible to make competitive decisions using the methodology proposed in the present research. As the welding length and programming time of products increases, the production quantity can decrease. Still, if the product life-cycle is at least one year, the batch size must fill one work shift per month in case of mini-loaders or base-frames and one work shift per week in case of hydraulic cylinders.

As one can see, the coefficient of product complexity C_{co} takes into consideration the difference of products but it can be shown that the product with smaller dimensions and fewer weldments is less complex than the bigger product requiring additional measurements. The complexity arises as the number of welds increases and therefore the technological sequence must receive more attention. As the dimensions of the product increase, the programming space expands and the complexity rises.

As an example, two different products are compared to show the influence of the complexity coefficient. They are the base frame of mini-loaders and the fuel-tank (see Fig. 3.4). The data about the products (welding length, the number of measurements, the number of weldings and volume) and complexity coefficient values are given in Table 3.6.

The estimation of programming time for the base frame of mini-loaders is between 32.2 and 58.4 h and between 5.1 and 9.3 h for the fuel-tank. The values are given as minimum and maximum as it depends on the duration of the used programming operations.

Table 3.6. Product data and overall complexity coefficient values of the base-frame and the fuel-tank

	l_w (m)	n_{me} (pcs)	n_w (pcs)	n_{cl} (pcs)	d_v (m^3)	Sum
Base-frame	15,1	8	92	8	0,53	
C_{co}	4	2	4	NA	2	3,1
Fuel-tank	5,55	0	25	4	0,075	
C_{co}	3	0	3	NA	1	1,75

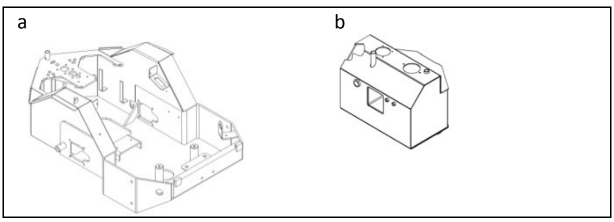


Figure 3.4. Mini-loaders' base-frame (a) and fuel-tank (b)

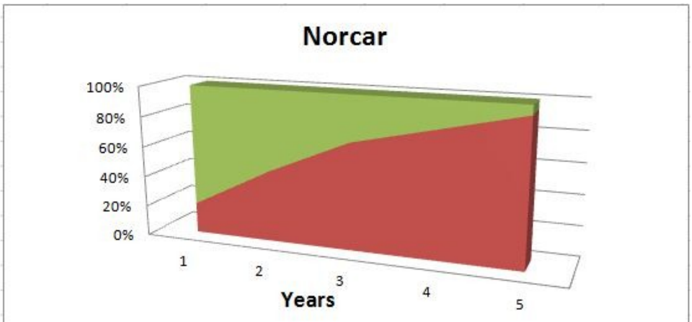
As the programming knowledge increases, the values can be refined by the enterprise specific data. For gathering such data additional sensors can be used in robot-welding cells. Wireless sensors are the most suitable, (Otto, 2011) as there are many moving parts in the system. It also gives a possibility to monitor the maintenance of the system.

3.4.2 Implementation chart development

The idea of the implementation chart is to give an overview of how long it takes to make the robot cell reach its full capacity. If more programs are introduced, the welding capacity may increase due to the shortage of products to be welded.

The implementation charts was introduced based on the data gathered from production. The data was analyzed and programming/welding ratio was established. During the implementation of three systems (Norcar, Stram, Norrhydro) the exploitation time of the robot was observed.

In Figure 3.5 the chart for the Norcar robot cell is shown. The implementation time is comparatively long, as there are over 40 products to put to use. The transition point is after 2,5 years, when the main programs have been made and the welding percentage increases rapidly. After that the programming time is connected with introducing some new products and with correcting the existing programs. In Figure 3.6 the chart of the Norrhydro robot cell is shown. The implementation time on-site was close to 7 months. As the products are mainly of cylindrical shape, the implementation of the new products was faster as the existing program modules could be reused. When the critical mass of the products was introduced, the programming time decreased to the minimum. In Figure 3.7 the chart of the Stram robot cell is shown. The implementation time on-site was about 4 months. The program was needed only for one product and it was fine-tuned considering welding parameters, welding positions and optimal working trajectories for the robot.



	1	2	3	4	5
programming	80	53	30	18	6
welding	20	47	70	82	94

Figure 3.5. Programming/welding ratio in Norcar

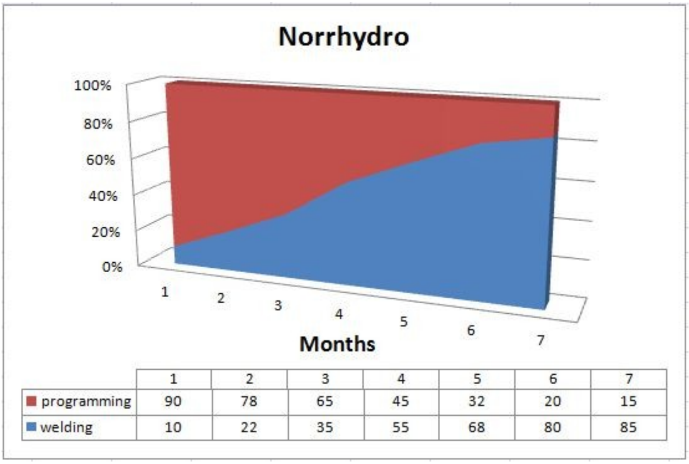


Figure 3.6. Programming/welding ratio in Norrhydro

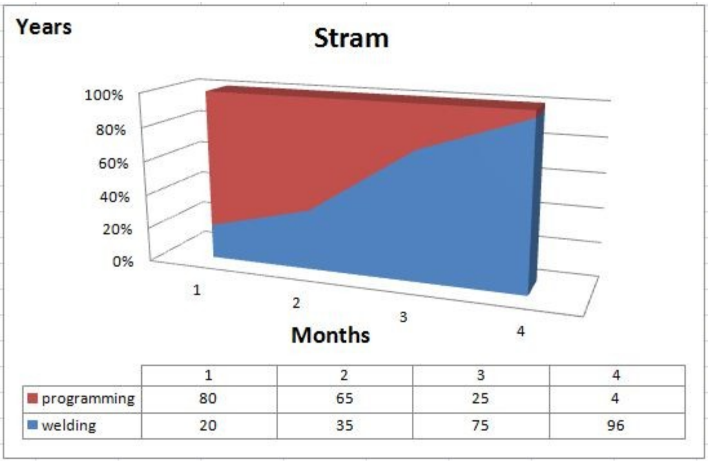


Figure 3.7. Programming/welding ratio in Stram

3.4.3 Grouping of the products for welding as the key to effectivity

The effectiveness of the implementation process of the robot welding cell depends on the suitable grouping of the products welded. The data was gathered from the real production process in Norcar BSB Eesti Ltd in the course of four years. The basis of the comparison is the production time/welding time ratio. As the production quantity fluctuates, the ratio must be calculated for different years. Subsequently, the products are divided into groups based on quantity (small, medium, large).

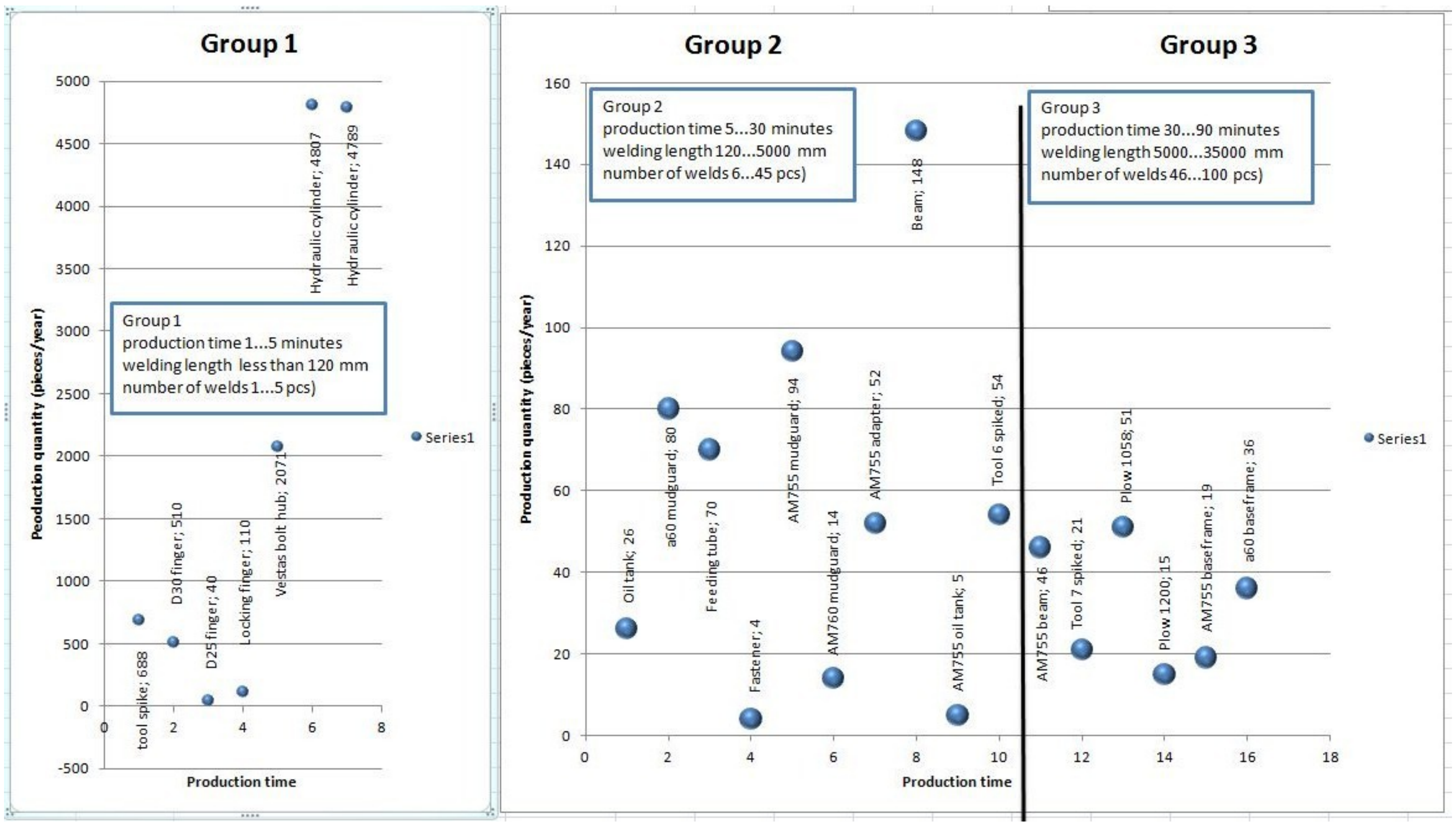


Figure 3.8. Grouping of the products based on welding time

To evaluate the efficiency for the implementation, the next characteristics should be considered:

- production quantity
- products by welding time
- calculations based on minimal, optimal and maximum time (further the average time replaces the optimal time)

Using the results of analyze the products grouping are presented in Fig 3.8. This graph can be used for grouping of the products based on four parameters: welding time, production quantity, welding length and number of welds, as these parameters influence the most of the grouping of the products. Based on gathered data from production and as a result of analysis the enterprise can establish the groups based on the product portfolio to be welded.

Based on the this the table 3.7 is formed.

Table 3.7. Comparison of welding time and production quantity

	Welding time	**Production quantity**	**Welding length**	**Number of welds**
Group	Minutes per product	Pieces per year	mm	pcs
1	1...5	Over 1000	less than 120	1…5
2	5...30	Over 100	120…5000	6…45
3	30...90	Over 10	5000…35000	46…100

3.4.4 DSM analysis for the implementation process

To get a complete overview of the implementation process, the DSM is a suitable tool for ordering the tasks and showing the interactions between them. All the necessary actions can be carried out in a serial, in a parallel or in a coupled mode. For completing the action-based analysis, a DSM for 14 inputs was compiled, characterizing all the necessary substantial activities during the implementation of the full robot welding cell (see Fig 3.9).

The next extended actions are needed during the selection, implementation and employment of the robot welding cell-given with a comment in brackets:

- charting of the products (the selection of suitable products);
- charting of the technology for the selected products (welding technology, understanding the process);
- evaluation of the product suitability (economy, robot welding cell);
- selection of the components for the robot welding cell (the selection of the positioner and the robot based on product suitablity analysis);
- the first simulation of the robot welding cell (3D simulation of the robot and the product);
- development of fixtures for production (the design of the jig based on welding technology);
- design of the robot welding cell, simulation with product and fixture (3D simulation, full system);
- programming of the production programs for the cell (based on the selected products and the defined modules, the programming takes place in 3D environment);
- installation of the full system (on-site installation);
- implementation (tuning, calibration);
- user training (welding technology, programming of the robot);
- welding tests, verification of welding technology (finding right parameters for welding);
- implementation of the technological process for the robot welding cell (includes product technology, jig properties, welding parameters);
- production planning, implementation of new products, (e-manufacturing, keeping track of productivity).

There is no need to arrange the inputs in order as it is sequenced by the mathematical treatment of this matrix. All inputs must be only preliminary numbered to give a possibility to include the synergy relations between the inputs of the matrix and therefore the numbers of the inputs must be the same on the horizontal and vertical axes. The number of the inputs is practically limitless and depends only on the complexity of the system. The strength of interaction synergy between inputs is characterized on a three-step scale: 2 – strong interaction, 1 – moderate interaction and 0 – indifferent (blank) interaction.

The right ascendancy of interactions is important to form coupled activities. The primary matrix has been allocated to sequencing transformation. In this process the activities are rearranged with the goal to move all the interaction under the diagonal that leads to the possibility to use the information of previously completed actions in a chain of activities. After the sequencing the new order of activities is established. Sometimes serial and parallel activities are possible. In some cases the solution of the current task needs some feedback information from the later activity and those related tasks are grouped into outlined blocks (Cho & Eppinger, 2001; Cho, 2001). So, the use of the DSM technology is a sound way for the expedient modularity of activities. The advantage of the DSM is the automated scheduling of activities granting that not one of them is missed or carried out without necessary information from previous activities. However, it is possible to make a further step – to make a probability prognosis of the duration of the whole robot cell implementation process.

Task Name	Level		1	2	3	4	5	6	7	8	9	10	11	12	13	14		
charting of the products	1	1		2			Block1										1	
evaluation of product suitability	1	2	1														2	
selection of the components for the robot welding cell	2	3		2		2				Block2							3	
first simulation of the robot welding cell	2	4		1	2		1										4	
development of fixtures for production	2	5		2	2	1											5	
charting the technology for the selected products	2	6	1	1													6	
design of the robot welding cell, simulation with the product and fixture	3	7	1	2	1		1			1							Block3	
programming of the production programs for the cell	3	8	1				1	2	1		1						8	
installation of the full system	3	9			1		1	1		1		1					9	
implementation (tuning, calibration)	3	10								1	2			2			10	
user training	3	11									2	1		1			11	
welding tests, verification of welding technology	3	12					1	2			1		1				12	
implementation of the technological process for the robot welding cell	4	13						2	1				1	1		1	13	Block4
production planning, implementation of new products	4	14				1		1						2	1		14	
			1	2	3	4	5	6	7	8	9	10	11	12	13	14		

Figure 3.9 Activity-based DSM after sequencing

This possibility proceeds from discreet event modeling, where the expected durations of tasks during each simulation are initially sampled using the LHS (Latin Hypercube Sampling) method. All this makes it possible to compute the probability distribution of lead-time, taking into account learning curves and probabilistic iterations among tasks (see Fig 3.10). This approach, which provides the mathematical background to the present thesis, has been available due to the cooperation of Prof. S. D. Eppinger and his research team in Massachusetts Institute of Technology (MIT).

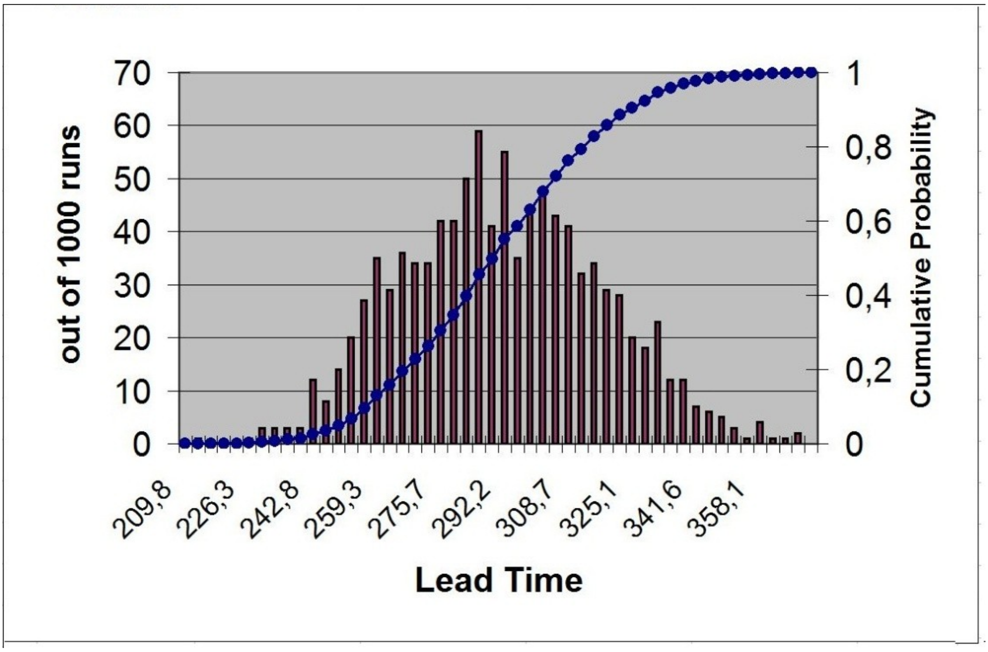


Figure 3.10 The expected duration of implementation process

3.5 Conclusion of Chapter 3

1. The implementation of welding robot cells in SMEs is an increasing trend. The proposed system decomposition technology based on the systems theory gives an advantage for SMEs at the implementation of complex technologies.

2. The layered approach gives a better overview of the system, its processes and the scale of economy that can be achieved. The proposed layered approach helps to prevent problems during the system setup and gives an approach how to share actions between different layers in the multi-agent context.

3. The estimation of programming time is a necessary tool for SMEs as it provides more flexibility when implementing new products on a robot welding cell. Also, it helps SMEs to improve competitiveness and refine the values with enterprise specific data.

4. An implementation chart is introduced, which takes into account welding time and programming time ratio, enabling to estimate when the robot welding cell reaches its full capacity. Therefore, the introduction of new products gets faster, as the operator acquires more skills and the created programs are reused.

5. The speed of the implementation process of the robot welding cell depends on the suitable grouping of the products to be welded. These groups can be formed on the basis of production quantity and welding time and it has to be taken into account when selecting products for the robot welding cell.

6. The DSM technology is a powerful tool for the expedient modularization of multi-agent production processes and for a prognosis of probabilistic implementation time of the robot welding cell.

4. SEARCH FOR POSSIBILITIES FOR INCREASING SYNERGY IN INFORMATION AND KNOWLEDGE MANAGEMENT IN MODELING CONTEXT

4.1 Avoiding shortcomings and looking for ways for empowering synergy

In this part of the research the main focus is concentrated on the teaching of technical subjects and especially on the training of the personnel to be connected with robot cell operating. Let's start from traditional digital concept maps. Siemens (2005) suggests that knowledge may not be restricted to "know-what" and "know-how" but has to be supplemented with "know-where" or where to find knowledge. In other words, it is necessary to know where to find the information, which may be used as a knowledge resource in resource-based learning (Neumann, Gräber & Tergan, 2005). Knowledge about where to find information relevant to a concept may be represented by means of interactive links leading the user to the information which is associated with a particular concept (Safayeni, Derbentseva & Canas, 2005). It is advised to use digital concept maps as the main vehicle for the storage of information in a repository for providing easy access (Weideman & Kritzinger, 2003) and as cognitive tools for the management of knowledge and information (Tergan, 2005).

There is another problem with concept maps in respect of their representational features as traditional concept maps have been used to describe, define and organise static knowledge for a given domain. The representation of dynamic relationships between concepts was not possible because of the predominance of hierarhical and static relations used for mapping. Only recently (Safayeni, Derbentseva & Canas, 2005) suggested cyclic concept maps for representing dynamic relations and hybrid maps for representing both the concept map an the cyclic concept map portion of a knowledge representation in an aggregated map. This is an encouraging trafficator for the present research.

The shortcomings of paper-and-pencil concept maps were overcome by computerized digital mapping tools. Many of these tools also offer facilities to represent multiple coded subject matter content knowledge in a map (e.g. text, sketches, diagrams, audio, and video). They make information stored on a PC, in a digital library, and on www-servers accessible by means of hyperlinking concepts and information (Alpert, 2003).

Shortcomings in technical facilities of **information visualisation** relate to some basic problems as information visualizations cannot compensate for a deficient data structure with a well-designed visualization. Therefore, information visualizations require well-prepared and well-structured data. Due to the fact that - contrary to hierarchical data structures - network data structures do not have a simple structure, the visualization of this data is still very difficult (Herman, Melancon & Marshall, 2000). The difficulty is that a computer display is limited in its size. Due to this limitation, it is difficult to visualize a large data set in such a manner that the user can perceive all data elements and can understand the data structure. In general, it has to be remarked that it is a big challenge for developers of information visualizations to find a well-suited metaphor or abstraction for a visualization of the abstract data (Le Grand & Soto, 1999), because the metaphor or the abstraction have to map the correct data structure, as well as convey the correct meaning of the data to the users. This is the second important trafficator.

So far the prerequisites of the user for dealing adequately with information visualizations and making sense of visualizations have not gained much attention. However, it is important to develop new technologies in alignment with the changing demands of the user. Therefore, it is necessary to include the experience and know-how of more user-oriented sciences, for example psychology. According to Marshall (2001), information visualizations often lack comprehensibility. It seems to be neccessary to include more textual elements in information visualizations to enhance visual semantics (Sebrechts, 2005) and to assure understanding, because symbols or other graphical object attributes could not mirror the complexity of the data units underlying an information visualization. As a result, it is important in the context of developing information visualizations to find a suitable trade-off with regard to the amount of textual elements included in the information visualization (Tergan, 2005). This seems to be the third important trafficator.

Summarizing the aforesaid, it is necessary to underline that it is possible to achieve higher level of **synergy** if the orientation, visual search, and cognitive processing of complex subject matter can be enhanced and if structures behind ideas, knowledge, and information, as well as their relevance for coping with a particular task, are made explicit. Despite common interest in facilitating content accessibility and making sense of represented knowledge and information elements by developing visual artefacts, not many attempts have been made to search for synergies for enhancing learning. There is a need for a systematic investigation into the potential of knowledge visualization, both for supporting self-controlled learning and for the use of knowledge and knowledge resources, in self-regulated, resource-based studying and problem solving (Tergan, 2005).

It is intelligible that **information and knowledge visualization** is to be organized in such a way that it may be accessed easily and comprehensively. The present research focusses on the attaining of synergy effects. Synergy effects may result with respect to the user-centeredness of visualizations, especially in the new field of dynamic-interactive visualizations. They both, information and knowledge visualization, use comparable techniques and methods of visualization and aim to support visual searching, localization, and individual utilization with concise, psychologically reasonable, and functional visualizations. Information visualization focuses on two-dimensional, as well as three-dimensional (or multi-dimensional), visualizations, whereas knowledge visualization restricts itself mainly to two-dimensional visualizations (Tergan, 2005). As far as information visualization is concerned, the consideration of knowledge mapping as an add-on or integral part of information visualization may be envisaged as a possible way out (Burkhard, 2005). These approaches clearly aim at integrating knowledge and information visualization in a coherent manner.

It is important to discriminate between two kinds of approaches: dealing with visualizations of knowledge and information to foster learning and instruction on the one hand, and visualizations of knowledge-oriented information organization to foster information use on the other hand.

4.2 Deployment of virtual module technology

Let's now turn from the theoretical and methodological treatment of information and knowledge back to their application ways. It is clear that the information extracted from products needs to be visualized. Therefore, a suitable model for information about expedient modularity has to be proposed. For the proposed modularisation information model it is best to choose a layered structure. Different levels of modularisation information can be inserted (interfaces – number, types, strengths; functional modules; interface drivers) into it. This information is extracted from product development (PD) at different stages of the process. This model can be named a "virtual module" acting as a carrier of the information listed above. The virtual module is defined here as a room for modularisation information and it helps to visualise the modularisation approach during the PD process.

The module informational model includes: PD process, abstraction level (product detail level) and modularity information (modularisation information/knowledge). When placing information concerning modularity into this model, the different methods/approaches are in different places (PD process vs abstraction level vs modularisation information). However, for every method its own room is reserved. The proposed module informational room in Fig 4.1 shows three approaches and their relative position in this room.

- Functional decomposition (1) – functional modules are placed into the start of the PD process where the abstraction level is high.
- MIM and drivers (2) are placed in the middle of the PD process. The product is now less abstract.
- Metrics (3) are placed at the end of the PD process where the product is on a more concrete level.

Recent studies (Breidert, et. al, 2003, Avak, 2006) show that the economy of production and sales can be achieved by using appropriate methods for modularising products. Those approaches are distributed over the (PD) process and they differ from each other on the level of modularity. During the modularisation process a large number of information/knowledge is always created. However, the information/knowledge obtained from this process is still defined unclearly and handled improperly. Approaches to managing information, which cover the overall PD process, seem to be still insufficient.

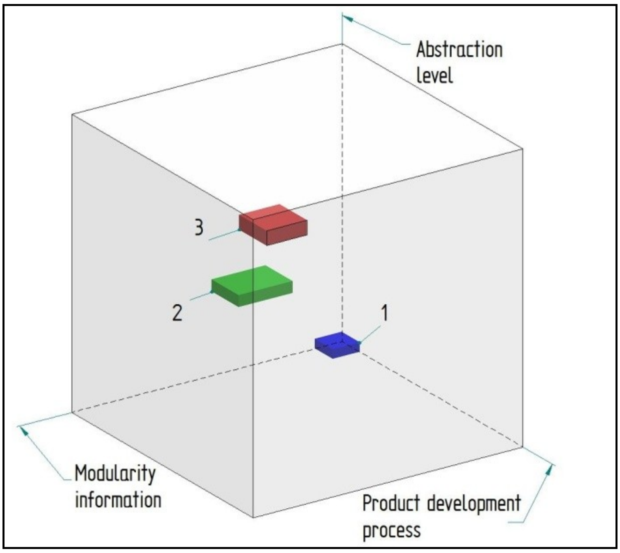


Figure 4.1. Module informational model

In Chapter 2 the modular products, forming product families, were analyzed. These products are a mobile phone test adapter, a luminary light source and smart dust. These products are analysed on different modularisation levels and in different PD process stages to gather information/knowledge about modularization effectivity. This information/knowledge is used for generating an informational modularisation model ("virtual module") proposal. This model proposal can be used as a roadmap for the management of modularisation information. The purpose of this research is to evaluate which type of information/knowledge concerning modularity is suitable to extract from the product and production process.

Support methods exist for the early phases of planning and conceptualisation/modularisation as well as for the late phases of evaluation/optimization. For the synthesis phase, however, the situation looks different. As the product is mainly customer specific, the modularisation methods and modules also differ from product to product, although the drivers and metrics can be defined as unique (Ishii & Yang, 2003). Therefore, to gain maximum benefit from modularity, the current situation concerning modularity information should be mapped and the informational room defined.

At the modularization of the production system three main directions must be considered:

- the physical world (real things and parts)
- the virtual world (3D models, policies)
- the information world (informational models which connects the real and virtual world)

In the process of modularization it is also feasible to distinguish the following steps: planning, conceptualisation and modularisation, synthesis, evaluation and optimization, configuration and this information interpretation is shown in Table 4.1.

Table 4.1. Modularisation information of the analyzed products

	Method/Approach	**Output/Info**
1	Functional decomposition	Functional modules Functional structure
2	MIM	Drivers Values Strengths Matrix
3	Metrics	PCI value CI value
4	Defining interfaces	Strength Type Interface structure

So, as a result of the analysis of the products and production processes, the modularisation information/knowledge about the product in different PD stages was extracted. The purpose of the extraction of this info is to visualize how much of the modularity information/knowledge stays unattended and is not reused. As a result, the domain of interfaces is added serving as a source of growing synergy in the modularization process.

4.3 Modularization and the layering of modules in the production systems of SMEs

By defining layers of complex system the visualization of information (knowledge) is helpful. The info extracted from system layers has to be clearly arranged. An arranged information model of complex system is proposed. The proposed information model has a layered structure. Different levels of system layers info can be inserted (hardware, software, policies) into it. This info (knowledge) can be extracted during system implementation at different stages of the process.

During system implementation the following layers of the system can be defined.

Product and production process analysing layer. Here, it is better to present the results of the analysis in the form of a technology chart. The example of the technology chart configuration is shown in Fig 4.2. This layer includes information about modules, virtual reality models, agents, database modules. In this layer the data about product welding technology, knowledge about welding sequence and calculation of production time is included. The analysis results are used for selection of suitable product for robot welding cell.

Drawing	663237			Welding parameters	v	w	I
					mm/s	m/min	A
Name	adapter			wld250v8sh11	8	7,5	250
Module number	M_105.mod			wld100v2sh12	2	8	100
Workstation	Station 2	STN2		wld250v6sh11	6	7,5	250
Workobject	Wobj663237			wld250v10sh11	10	7,5	250
Programming time	700	min		wld200v6sh14	6	12	200
ROBOT TIME		min		wld100v4sh16	4	8	100
Welding time	13	min		wld150v9sh15	9	9	150
Positioning time	5	min		weld100v6sh16	6	8	100
Maintenance	4	min		wld150v9sh15	9	9	150
OVERALL TIME 1	22	min		wld200v8sh14	8	12	200
Leadtime				wld200v14sh14	14	12	200
Jig setting time	15	min		wld70v6sh19	6	10	70
Loading time	7	min		wld50w6u4	6	6	50
OVERALL TIME 2	22	min		wld100v8sh16	8	8	100

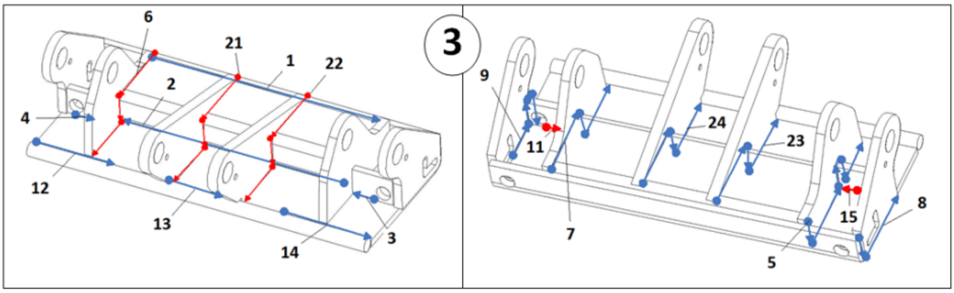


Figure 4.2. Technology chart for the robot-welding cell in Norcar (area 1 – program parameters, area 2 – welding parameters, area 3 – welding directions and sequence)

System configuration layer. Here, based on the technology analysis, the system hardware can be selected. The virtual system configuration can be compiled as shown in Fig 4.3. This layer includes information about modules, virtual reality models, agents and the functional diagram. This enables the selection of the right components for the robot welding cell based on the analysis of the products. During this process several cell concepts are worked out.

System simulation layer where the testing of the feasibility of the system and product by using virtual reality software (CAD, RobotStudio) takes place. This simulation is usually presented out of enterprise before the decision about buying/licensing the hardware. This layer includes information about: modules, virtual reality models, agents, functional diagram and technological modules. Based on the approved concept of the robot welding cell the final concept is fully simulated including all work movements and checking reachability.

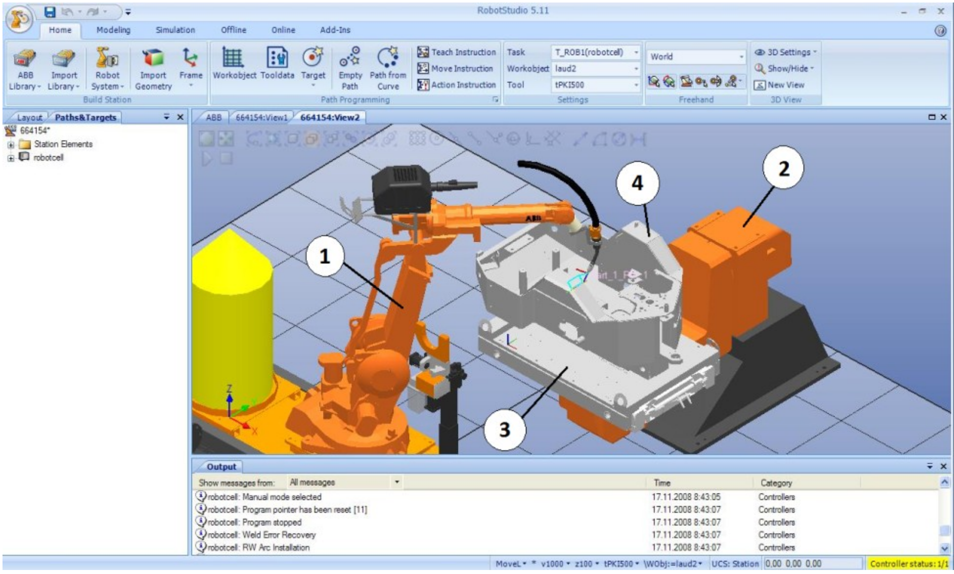


Figure 4.3. Virtual environment for system and product testing in Norcar (1 – robot, 2 – product manipulator, 3 – jig, 4 – product)

Facility layer – this layer is bound to the real system installation in the factory. Usually, here the CAD and virtual reality information must be updated. This layer includes information about agents and functional diagrams. This layer can also be treated as a stage of the previous system simulation layer or as a part of the next installation layer. However, in the real system installation process it is timely appropriate to consider the territorial difference.

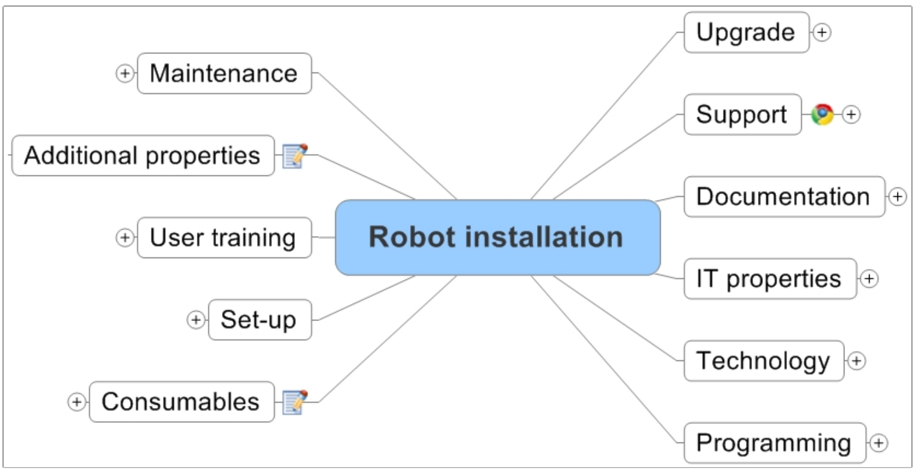


Figure 4.4. System installation layer in the robot-welding cell in Stram

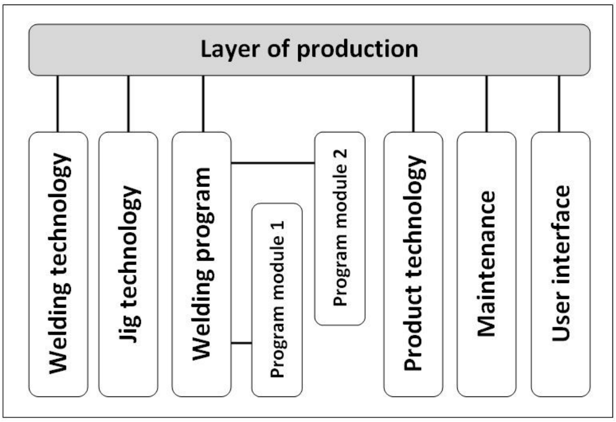


Figure 4.5. Information included in the production layer

Robot installation layer. This layer consists of all information and policies for the support of system installation in a real factory. In Fig 4.4 the topics provided during installation are shown. This layer is indisputably the most extensive and many-sided. However, due to the close interaction of its activities it is not appropriate to divide its components into different layers.

Jig layer. Principally, here it is necessary to connect the system and the product with each other. This layer includes information about modules, virtual reality models, agents. This layer is not simple as the jig must be designed to be multifunctional and easily adaptable to future products.

Programming layer. This layer includes all program modules, welding positions, and additional modules.

Layer of production – production in the real world, welding parameters. In Fig 4.5 the main issues concerning this layer are shown. This layer includes information about policies, modules, agents.

Modules can be associated with every layer where it is neccessary. Modules (product, process, program) represent the important data about the products or processes and help share information between layers. For example, product technological module information can be used for the modularization of the production program or for the definition of jig modules.

In the conditions of SMEs the visualization of information (knowledge) is a useful tool for defining the layers of a complex system. The next level of sharing information and decisions between layers in the **virtual room** is by use of agents. Their use can be helpful for making decisions about product suitability for production in the robot welding cell or about jig suitability for concrete product production. At first the information extracted from system layers has to be clearly arranged. Different levels of system layer information must be inserted (hardware, software, policies) into it. It is possible to extract this information (knowledge) during system implementation at different stages of the process. The proposed model is called a “virtual info room” and acts as a carrier of the information (knowledge) about the system. This model can have as many layers as needed depending on the system complexity and its possible structure shown in Fig 4.6.

This model can be filled with system information and process knowledge during the system creation phase. By having a layered structure, it is easier to grasp system properties and move between layers to understand interconnections between the different parts of the system. Each layer can be defined with a distinct detail level. Also, it is possible to move between these layers and update them with additional information (knowledge). If a complex system is used for production, the leading layer can be connected with production.

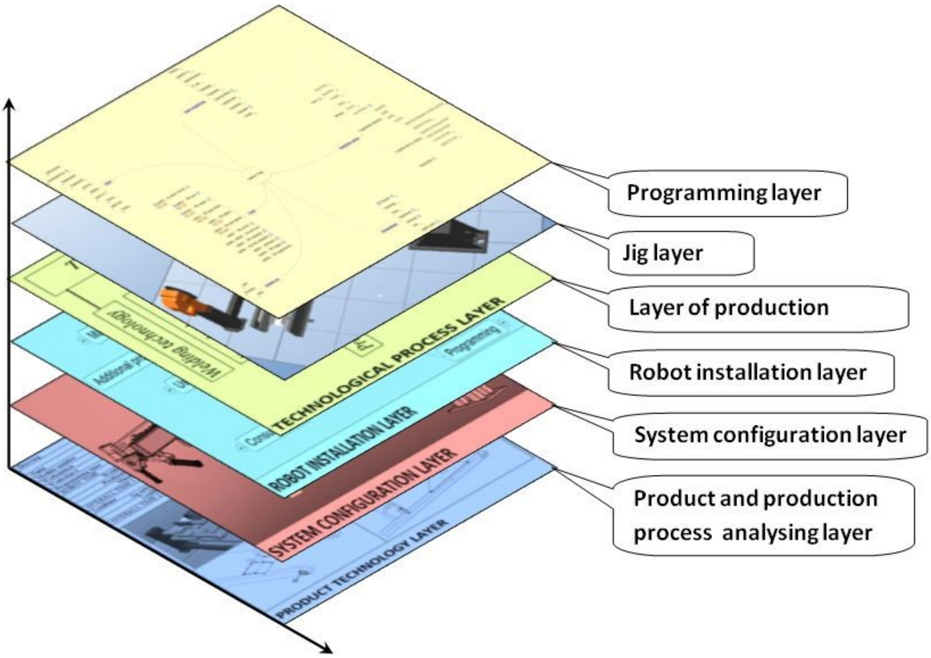


Figure 4.6. Layered virtual room for complex system implementation

By dividing the complex system into layers and by connecting layers with modules, it is possible to use software agents, which enable communication between layers. The subsequent model is shown in Fig 4.7 where modules share information between layers and agents share decisions. Decisions by the agents can be made based on several criteria which are defined in the layer. For example, the decision about product suitability for robot welding is a multi-criterion problem where product dimensions, welding length, number of welds etc. play an important role in decision making.

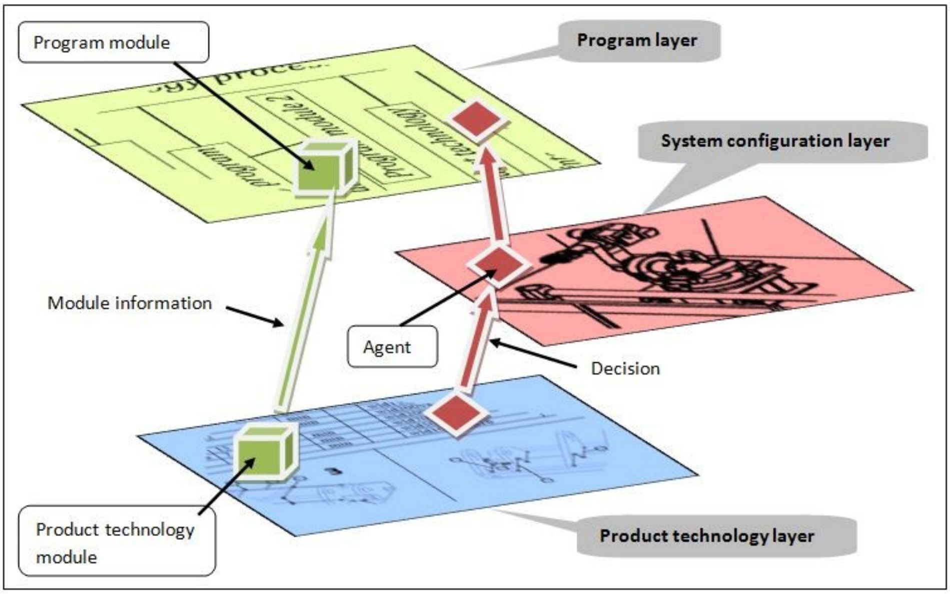


Figure 4.7. Sharing information between modules and decisions between agents

4.4 Proposal for an expert system for the selection of the structure of the robot welding cell

The expert system for the selection of the structure of the robot welding cell is based on a virtual layered module. The database blocks are formed based on this approach. The structure of the main blocks of the database are defined as follows:

- Product technology block;
- Welding technology block;
- Welding jig block;
- Robot welding cell components/selection block;
- Economic calculation block.

Based on this division, the architecture of the database is created. The purpose of this expert system (database) is to support the selection of the components of the robot welding cell (robot, positioner, welding power source, jig) to describe the welding technology of products, for the selection of the welding jig and for economic calculations (price of welding, estimated price of robot welding cell, jig price, payback time).

The database engine is based on pgAdmin (PostgreSQL database) and the user interface is created using the Java language. The solution of the database user interface is shown in Fig 4.8.

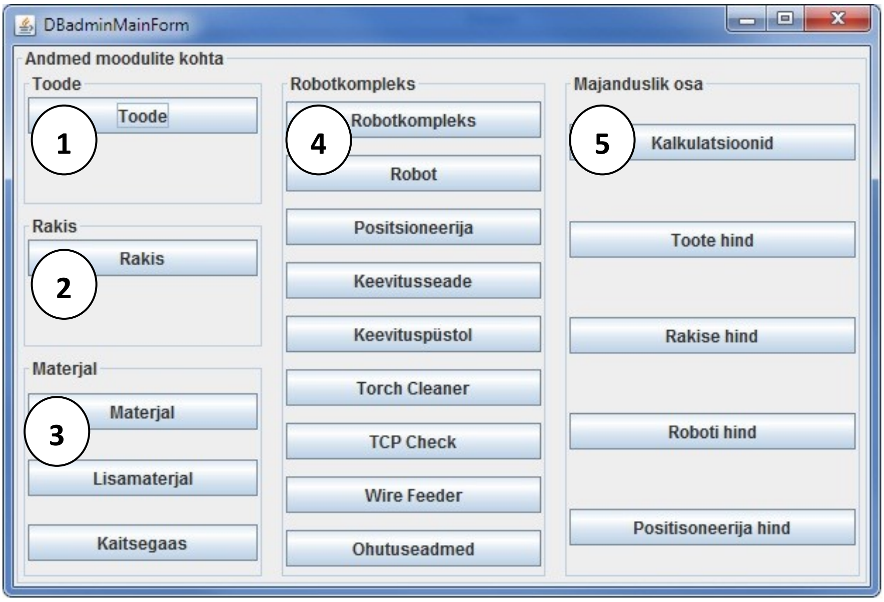


Figure 4.8. Example of the database user interface (1 – product block, 2 – jig block, 3 – technology block, 4 – robot cell block, 5 – economic calculation block)

Product technology block is used for input of the product data which is needed for decision of the suitability for welding in robot cell. The input data includes product name, number, volume, mass, estimated production quantity. The product data is connected with welding technology data like welding parameters, welding length, dimension of weldment and welding materials needed

Welding technology block includes the specifications about weldable materials, additional materials, welding gases and welding parameters. By connecting this information with product data the economic calculations can be made about the welding costs.

Welding jig block includes the specifications of main welding jig solutions. It includes the guides for designing of the welding jig depending of the product specification. Also the 3D models are included for reference.

Robot welding cell components/selection block includes the information about the robot cell main components (robot, positioner, welding equipment, safety equipment, additional equipment). Several solutions of the robot welding cell configurations are included to make selection of the suitable cell straightforward.

Economic calculation block concentrates the calculation data from previous blocks and additional calculations can be made about the ROI and the implementation period.

4.5 Conclusions of Chapter 4

1. Information and knowledge visualization allows to use several multimedia possibilities (animations, colour pictures) helping users to better understand the product and production process. Participants from enterprises should be offered tailored schemes for different levels, consisting of selected subtopics.

2. There exist a wide range of modularisation methods that support the PD process on different modularisation levels. In different PD stages the modularisation information/knowledge about the product is substantial. The purpose of the extraction of this information is to visualize that much of modularity information/knowledge stays unattended and is not reused properly. The proposed approach tries to define an informational model about modularity. To gain maximum benefit from modularity, the current situation concerning modularity information should be mapped for every enterprise individually.

3. Configuration of robot welding cells using the division of tasks enables to introduce complex technologies in SMEs. Layered structure decreases the implementation time of the whole system by enabling parallel integration of different sub-systems.

4. An approach to the virtual module, complex system layering and the concept of the expert-system is proposed. They act as tools for the selection of modularization methodologies, dividing complex systems and selecting products for the robot-welding cell. A knowledge/information model for each approach is presented giving engineers invaluable tools for system implementation.

5. The expert system for robot welding cell configuration enables the selection of robot-system components, implementing the suitable products and economic calculations. This tool gives an edge to the enterprises reducing the implementation time of new products and robot systems.

6. One goal of the current research was the idea to start the modularization earlier in the product development process. So, the product, production process and production equipment were bonded together, which enables to reuse the acquired knowledge in different development areas at the same time.

CONCLUSIONS

It is appropriate to discuss the findings of the present thesis in three aspects: research results and their applications, novelty of findings and the need for further research. During the doctoral research the following conclusions have been reached:

1. All objects of the present research – modular products and robot systems – belong to the category of complex nonlinear systems, which makes their analysis more complicated as it is necessary to use soft computing tools. As modern production systems are a complicated mix of information technology, intelligent production equipment and operators, the multi-agent intelligent system philosophy seems to be a suitable meta-approach for the optimization of such systems. So the key to the optimization is the empowerment of the synergy in information and knowledge management allowing to achieve economic solutions of classical automatization technology also under the conditions of SMEs, where the precondition is the use of adaptive system design tools based on team competence.

2. The analysis of the three eventually different products (the adapter, the luminary light source, smart dust) shows that the use of expedient modularization methodology is of great importance in the conditions of SMEs. Rational Product Life Cycle Management (PLM), with the involvement of product platforms, families and redesign, is impossible without the modularization of products and also production processes. Dividing products into modules and defining platforms enables the designers to better comprehend/manage the overall system and reuse the approved solutions when designing new products.

3. The synergetic effect of the modularization is shown through the reuse of the acquired knowledge during the modularization process, which can be charted using visualization mediums. It is shown that the development time of new products decreases significantly by reusing suitable modules and through knowledge management. For this purpose it is recommended, for example, to compile an Adapter Design Book (ADB) for the enterprise to describe the test adapter product platform where the recommended modules are also included with the engineering knowledge they carry.

4. The implementation of the three robot welding cells has proved that the introduction of complex production systems in the conditions of SMEs is possible through domain-based partitioning and modularization. By dividing the complex systems into manageable parts the implementation process and configuration of robot cells can be accelerated and the probability of the success of the project increases.

5. For the implementation of complex production systems, a selection methodology, an implementation chart and an equation for the calculation of programming time are proposed. Through the use of these tools the synergetic effect is achieved as they include the interactions of the operator, production system and product. The novelty of these approaches consists in the included interconnections between the operator's competence, product complexity and robot welding cell configuration. As validation an implementation chart is introduced, which takes into account welding time and programming time ratio, enabling to estimate when the robot welding cell reaches its full capacity. Therefore, the introduction of new products gets faster, as the operator acquires more skills and the created programs are reused.

6. Three tools for engineers are introduced: the virtual module, the layering of complex systems and expert systems for the robot welding cell. The concept of the virtual module is proposed for the improvement of the navigation on the modularization scenery to enable ordering of the modularization activities during the product development and production process. The layering of complex systems supports the description (visualization) of the complex systems containing layers, modules and agents. The layered approach gives a better overview of the system, its processes and the scale of economy that can be achieved. The proposed layered approach helps to prevent problems during the system setup and gives an approach how to share actions between different layers in the multi-agent context. The expert system for the robot welding cell is suitable for product technology charting, robot cell selection and economic calculations.

7. The DSM technology is a powerful tool for the expedient modularization of multi-agent production processes and for a prognosis of probabilistic implementation time of the robot welding cell. However, the speed of the implementation process of the robot welding cell also depends on the suitable grouping of the products to be welded. These groups can be formed on the basis of production quantity and welding time and they have to be taken into account when selecting products for the robot welding cell.

8. One goal of the current research was the idea to start the modularization earlier in the product development process. So, the product, production process and production equipment were bonded together, which enables to reuse the acquired knowledge in different development areas at the same time. So the concept of the virtual model was introduced. This is proved through the case of the implementation of the robot welding cell, which is used as an experimental base for revealing these relationships and synergy increase through layers, modules and agents.

The novelty of the present research is concerned with the next key notions: the virtual module, system layering and synergy deployment. The introduction of the virtual module enables to move in the complex modularization scenery during the development of the new products by reusing the acquired knowledge from previous design activities. The layering approach of complex production systems enables SMEs to decrease the implementation time of complex production systems. It is based on domain-based partitioning, expedient modularization and the concept of multi-agents. In the present research, synergy is used in its quantitative form that means the deployment of synergy through the compensation of mutual weaknesses between the components integrated at the design of production processes and the amplification of their common useful effects. For attaining a better synergy in the development process, the principle of expedient modularization is recommended to use where the design activities are also modularized, enabling to start modularization from the very beginning of product development. It makes it possible to introduce synergy relations between the agents involved on the modular level.

The future research is connected with complex production systems with the main focus on implementing new technologies and improving the existing ones in the conditions of SMEs. Considering the welding process, an in-depth research is needed for the charting of parameters and selection methodology of MIG welding parameters for different material types and thicknesses. Based on the acquired knowledge during this process and by connecting novel approaches (sensors, cameras, real time computing), the development of the on-site welding calibration/tuning tool is considered to be appropriate. Also, the database development for the management of production parameters and production quantity is considered for use in complex production systems as the e-manufacturing tool in the conditions of SMEs.

KOKKUVÕTE

Doktoritöö peamiseks eesmärgiks oli uurida võimalusi süsteemse sünergia suurendamiseks läbi intelligentsete multi-agentsete tootmissüsteemide otstarbeka võimalikult varajase modulariseerimise ning ratsionaalse informatsiooni ja teadmuste visualiseerimise abil.

Selleks, et antud eesmärgini jõuda, tuli doktoritöös lahendada tööülesannetena järgmised olulised probleemid:

1. Saada ülevaade teadusuuringute seisust keerukate süsteemide sünteesi ja optimeerimise valdkondades;
2. Keerukate toodete ja tootmisprotsesside otstarbeka modulariseerimise võimaluste hindamine;
3. Multi-agentsete protsesside modulariseerimise optimeerimine keerukate tootmissüsteemide evitamise näitel;
4. Sünergia mõju suurendamise võimaluste analüüs informatsiooni ja teadmuste haldamisel, lähtudes modelleerimise protsessi vajadustest.

Uurimistöö esimeses ülevaatlikus osas on põhitähelepanu suunatud modulariseerimismetoodikate analüüsile, keerukate süsteemide olemuse kirjelduse viisidele, sünergia suurendamise võimalustele ning teadmuste ja informatsiooni kaardistamise vajalikkusele.

Töö teises osas on analüüsitud kolme toote, mobiiltelefonide testadapter, päevavalgusti ja tark tolm, modulariseerimise võimalusi. Analüüsi tulemusena ja erinevaid modulariseerimismetoodikaid kasutades on välja töötatud modulaarsed tooteplatvormid ja nende struktuuri vajalikud andmemudelid. Samuti on sellesse kaasatud sõltuvuste struktuurimaatriksite (DSM) tehnoloogia, mis on osutunud sobilikuks töövahendiks keerukate süsteemide analüüsil.

Kolmandas peatükis on välja arendatud keerukate tootmissüsteemide modulariseerimise põhimõtted. Töö käigus on analüüsitud kolme robotkeevituskompleksi juurutamist väike- ja keskmise suurusega ettevõtete (VKE) tingimustes. Selle tulemusena on jõutud järeldusele, et keerukate süsteemide kasutuselevõtt VKE-s on otstarbekas läbi nende valdkondadepõhise jaotamise osadeks, kaasates modulariseerimist ja DSM tehnoloogiat. Samuti on välja töötatud valikukriteeriumid sobiliku toote valikuks robotkeevituskompleksis keevitamiseks, valem programmeerimisaja leidmiseks ning robotkeevituskompleksi konfiguratsioonist sõltuvad juurutuskõverad. Kõigi nende tegevuste eesmärgiks on süsteemi parema sünergia saavutamine.

Töö viimane osa on pühendatud toote, tootmisprotsessi ja tootmiskeskuse juurutamisel või modulariseerimisel tekkinud informatsiooni ja teadmuste visualiseerimisele. Pakutakse välja sobilikud visualiseerimisvahendid, mis tagavad süsteemide kirjeldamise efektiivsuse. Kõige selle tulemusena on välja töötatud virtuaalse mooduli kontseptsioon, mis võimaldab keerukal modulariseerimismaastikul otstarbekalt liikuda toote algsest ideest kuni selle valmimiseni. Lisaks on välja töötatud keerukate süsteemide kaardistamise jaoks süsteemi kihtideks jaotamise virtuaalne mudel, mis sisaldab süsteemi erinevate kihtide kirjeldust koos modulariseerimisalase infoga ning seoseid agentidega. Viimasena on pakutud välja robotkompleksi ekspertsüsteem, mis võimaldab kasutajal siduda sobiliku toote, robotkompleksi ja rakise ning teha vajalikud majanduslikud kalkulatsioonid. Suurt tähelepanu on pööratud sünergia suurendamisele informatsiooni ja teadmuste haldamisel.

Töö lõpuosas on esitatud järeldused, antud hinnang uudsetele tulemustele ning lisatud soovitused edasisteks uurimustegevusteks.

Töö tulemusena on jõutud järgmistele järeldustele:

1. Kõik antud uurimistöös käsitletud objektid – modulaarsed tooted ja robotsüsteemid – kuuluvad keerukate mittelineaarsete toodete kategooriasse, mis teeb nende analüüsi keeruliseks, kuna on vaja kasutada uusi tarkvaralisi lahendusi (*soft computing*). Kuna kaasaegsed tootmissüsteemid on keerukas segu infotehnoloogiast, intelligentsetest tootmisseadmetest ja operaatoritest, siis on multiagentsete intelligentsete süsteemide filosoofia sobivaks metalähenemise viisiks nende süsteemide optimeerimisel. Üheks võtmeküsimuseks optimeerimisel on sünergia võimendamine läbi informatsiooni ja teadmuste haldamise, mis võimaldab saavutada klassikalisel automatiseerimisel majanduslikult otstarbekaid lahendusi ka VKE-de tingimustes, kus eeltingimuseks on meeskonna kompetentsil põhinevate adapteeruvate töövahendite kasutamine süsteemi projekteerimisel.

2. Kolme põhimõtteliselt erineva toote (adapter, päevavalguslamp, tark tolm) analüüsi tulemus näitab, et otstarbekas modulariseerimine on suure tähtsusega ka VKE-de tingimustes. Mõistlik toote elutsükli ohjamine (PLM) koos tooteplatvormide, perekondade ja taaskasutamise põhimõtete rakendamisega on võimalik ainult toodete kui ka tootmisprotsesside modulariseerimisega. Toodete mooduliteks jaotamine ning platvormide defineerimine võimaldab projekteerijail paremini haarata/hallata kogu süsteemi ning taaskasutada edukaid lahendusi uute toodete konstrueerimisel.

3. Modulariseerimise sünergiline mõju on saavutatav läbi modulariseerimisprotsessis kogutud teadmuste taaskasutamise, mida on vaja kaardistada visualiseerimisvahendeid kasutades. On tõestatud, et uute toodete konstrueerimisaeg lüheneb märkimisväärselt, kui kasutada sobilikke mooduleid ning teadmuste haldamise viise. On soovitatav koostada adapteri disaini käsiraamat ettevõttele, et kirjeldada testadapteri tooteplatvormi ja kus soovitatavad moodulid on sidestatud teadmustega, mida need kannavad.

4. Kolme robotkeevituskompleksi juurutamise näitel on tõestatud, et keerukate tootmissüsteemide evitamine VKE-de tingimustes on võimalik läbi süsteemi valdkonnapõhise jaotamise ja modulariseerimise. Jaotades keerukad süsteemid hallatavateks osadeks, on võimalik juurutusprotsessi ning robotkomplekside seadistamist kiirendada ning suurendada projekti edukuse tõenäosust.

5. Keerukate tootmissüsteemide evitamise kiirendamiseks on uuringute tulemusena loodud järgmised töövahendid: toote valiku metoodika, juurutuskõver efektiivsuse hindamiseks ja programmeerimisaja arvutusvalem. Need töövahendid aitavad saavutada efekti tänu operaatori, tootmissüsteemi kui ka toote omavahelistele seoste sünergiale. Antud lähenemiste uudsus seisneb selles, et nad sisaldavad vastastikust sidudust operaatori kompetentsi, toote keerukuse ja robotkeevituskompleksi konfiguratsiooni vahel. Selle tõestuseks on esitatud juurutuse graafik, mis võtab arvesse keevitusaja ja programmeerimisaja suhet, võimaldades ennustada hetke, millal robotkeevituskompleks saavutab oma maksimaalse võimekuse. Tänu operaatori kompetentsuse tõusule ning olemasolevate programmide taaskasutamisele muutub uute toodete juurutamine kiiremaks.

6. On loodud kolm kõrgema taseme töövahendit: virtuaalne moodul, keerukate süsteemide kihtideks jaotamine ja ekspertsüsteem robotkeevituskompleksile. Virtuaalse mooduli kontseptsioon parendab navigeerimist modulariseerimismaastikul ning võimaldada järjestada modulariseerimistegevusi tootearendusprotsessi käigus. Keerukate süsteemide kihtideks jaotamine toetab keerukate süsteemide kirjeldamist (visualiseerimist), kasutades kihte, mooduleid ja agente. Kihiline lähenemine võimaldab saada süsteemist ning protsessist parema ülevaate ning saavutada majandusliku kokkuhoiu. Kihtideks jaotamine aitab vähendada probleeme süsteemi paigaldamisel ning annab juhised, kuidas jaotada tegevused erinevate kihtide vahel multi-agentsuse tingimustes. Robotkeevituskompleksi ekspertsüsteem on sobilik toodete tehnoloogia kaardistamiseks, robotkompleksi komponentide valikuks ning majanduslike kalkulatsioonide sooritamiseks.

7. DSM tehnoloogia on efektiivne töövahend multi-agentsete tootmisprotsesside õigeaegse ja otstarbeka modulariseerimise tarvis ning tõenäose robotkeevituskompleksi evitusaja prognoosimiseks. Samas sõltub robotkeevituskompleksi evitusprotsessi kiirus veel keevitatavate toodete sobilikust grupeerimisest. Antud grupid on võimalik luua tootmiskogusest ja keevitusajast lähtudes ning neid tuleb arvesse võtta, kui valida tooteid robotiseeritud keevitamiseks.

8. Antud töö üheks eesmärgiks oli tagada tootearendusprotsessi modulariseerimine võimalikult vara ja otstarbekalt. Seetõttu seoti toode, tootmisprotsess ja tootmisvahend omavahel, mis võimaldab taaskasutada tekkinud teadmusi erinevates arenguvaldkondades. Sellega seondub ka virtuaalse mudeli idee. Kasutades eksperimentaalse baasina robotkeevituskomplekside juurutamisi, tõestati sünergia suurenemine läbi kihtide, moodulite ja agentide koostöö.

Käesoleva doktoritöö uudsus on seotud järgmiste märksõnadega: virtuaalne moodul, süsteemi kihtideks jaotamine ja sünergia suurendamine. Virtuaalse mooduli kasutuselevõtt võimaldab liikuda keerukal modulariseerimise maastikul uute toodete tootearendusprotsessi käigus ning taaskasutades saadud teadmusi eelmistest konstrueerimistegevustest. Kihtideks jaotamise lähenemine keerukatele tootmissüsteemidele võimaldab VKE-del vähendada keerukate tootmissüsteemide juurutamise aega. See põhineb valdkonnapõhisel tegevuste jaotamisel ja otstarbeka modulariseerimise kasutamisel ning multi-agentide kontseptsioonil. Antud uurimistöös on käsitletud sünergia kvantitatiivset vormi, mis seisneb sünergia suurendamisel kompenseerimaks vastastikuseid nõrkusi süsteemi integreeritud komponentide vahel ning võimendamaks nende ühiseid kasulikke toimeid. Saavutamaks arendusprotsessis suuremat sünergiat on soovitav kasutada otstarbeka modulariseerimise põhimõtteid ka konstrueerimistegevuste modulariseerimisel, mis võimaldab alustada tootearendusprotsessis modulariseerimisega võimalikult vara.

Hindamaks töö edasisi arenguid, tuleks rõhutada kolme võimalikku suunda. Üheks arengusuunaks on keerukate tootmissüsteemide rakendus läbi uute tehnoloogiate kasutuselevõtu ning olemasolevate tehnoloogiate täiendamine VKE-de tingimustes. Keevitusprotsessi osas oleks vaja teha süvauuring MIG protsessi keevitusparameetrite kaardistamiseks ja valikumetoodika väljatöötamiseks erinevate materjalitüüpide ja -paksuste korral. Tuginedes antud protsessis kogutud teadmustele ning kaasates ka uudseid vahendeid (andurid, kaamerad, reaalajaline arvutamine), on vajalik välja töötada tehases kasutamiseks sobiv kalibreerimis-/häälestustööriist keevitusprotsessi seadistamiseks reaalajas. Lisaks on vajalik välja töötada andmebaas tootmisparameetrite ja -koguste haldamiseks, et võimaldada kasutada e-tootmise põhimõtteid VKE-de tingimustes.

ABSTRACT

The objective of the present doctoral research was to study the possibilities of increasing synergy between knowledge and information visualization at the early evaluation of the expedient modularity of intelligent multi-agent production systems. The doctoral research is focused on the following fields: modularization of products and production processes, decomposition of complex systems (modularization, layering) and knowledge management in the conditions of SMEs.

In the first part of the research a thorough analysis of modularization methodologies, the essence of complex systems, synergy deployment and charting of information and knowledge are given.

The second part includes a modularization analysis of three products: the test adapter for cellular phones, the luminary light source and smart dust. As a result, modular product platforms and necessary data models of their structure are worked out. Also, the Dependency Structure Matrix (DSM) technology is proposed, which is a suitable tool for analyzing complex systems.

In the third part product modularization principles for the modularization of complex production systems and partitioning are developed. During the research the implementation of three robot welding cells are analyzed in the conditions of SMEs. As a result, it is shown that the implementation of complex production systems in the conditions of SMEs is possible through domain-based partitioning, modularization and DSM technology. Also, a methodology for the selection of a suitable product for the robot welding cell, an equation for the calculation of programming time and implementation charts for different configurations of robot welding cells are given. During all these activities the attaining of better synergy is an important issue.

The last part of the thesis is fully devoted to the visualization of the information and knowledge obtained from the modularization and implementation of the product, production process and production equipment. Possible visualization tools are presented, which give an effect for description of such systems. As a result, the concept of the virtual module is provided, which enables moving in the modularization scenery from the initial product concept to the finished complete product. For the charting of complex systems a layering methodology is given, which includes the description of the different layers of the system with modularization information and agents. An expert system for the robot welding cell is introduced, which enables the user to select the suitable product, welding jig, robot cell and to make economic calculations. A lot of attention is paid to synergy deployment in information and knowledge management.

Finally eight conclusions, novel findings and recommendations for further research activities are discussed.

Keywords: modularization, product development, complex system implementation, synergetics, robot welding cell, synergy-based optimization

REFERENCES

Alpert, S. R. 2003. Abstraction in Concept Map and Coupled Outline Knowledge Representations. *In:* Journal of Interactive Learning Research, 14(1), pp. 31-49

Avak, B. 2006. Life cycle adaption of modular product families. *In:* Proceedings of NordPLM`06 - 1st Nordic Conference on Product Lifecycle Management (Malmqvist J., Ström, M., eds.). Sweden, Göteborg, pp. 199-210

Baddeley, A. D. 1998. Human memory, Boston: Allyn&Bacon

Baldwin, C. Y., Clark, K. B. 2000. Design Rules. The power of modularity. Volume 1, The MIT Press, Cambridge, Massachusetts

Bhangale, P. P., Agrawal, V. P., Saha, S. K. 2004. Attribute based specification, comparison and selection of a robot. *In:* Mechanism and Machine Theory, **39**, pp. 1345-1366

Blackenfelt, M. 2001. Managing Complexity by Product Modularization: Balancing the Aspects of Technology and Business During Design Process. Doctoral Thesis, Royal Institute of Technology (KTH), Stockholm

Breidert, J., Welp, E. G. 2003. Tools supporting the development of modular systems. *In:* Proceedings of ICED 2003, International Conference on engineering design (Gralen, K., Andreasen, M. M., eds.), Stockholm

Browning, T. 1998. Modeling and Analyzing Cost, Schedule, and Performance in Complex System Product Development. Doctoral Thesis, Massachusetts Institute of Technology (MIT), Cambridge

Bruccoleri, M. 2007. Reconfigurable control of robotized manufacturing cells. *In:* Robotics and Computer-Integrated Manufacturing, 23, pp. 94-106

Burkhard, R. A. 2005. Towards a Framework and a Model for Knowledge Visualization: Synergies Between Information and Knowledge Visualization. *In:* Knowledge and Information Visualization. Searching for Synergies. Springer-Verlag, Berlin, Heidelberg

Buzan, T. 1995. The Mind Map book. Second edition. London, BBC Books

Card, S. K., Mackinlay, J. D., Shneiderman, B. 1999. Information visualization. *In:* Information visualization. Using vision to think. San Francisco: Morgan Kaufmann, pp. 1-34

Carr, D. 1999. Guidelines for Designing Information Visualization Applications. *In:* Proceedings of ECUE´99, Ericsson Conference on Usability Engineering

Clarkson, P. J, Simons, C., Eckert, C. 2001. Predicting Change Propagation in Complex Design. *In:* Proceedings ASME DETC-2001, Paper No DETC2001/DTM-21698

Cho, S. H., Eppinger, S. D. 2001. Product Development Process Modelling Using Advanced Simulation. *In:* Proceedings of ASME Design Engineering Technical Conference DETC'01, Pittsburg, Pensylvania

Cho, S. 2001. An Integrated Method for Managing Complex Engineering Projects Using the Design Structure Matrix and Advanced Simulation. M.Sc thesis. MIT, Cambridge, USA

Cox, R. 1999. Representation, construction, externalized cognition and individual differences. *In:* Learning and Instruction, 9, pp. 343-363

Dansereau, D. F. 2005. Node-Link Mapping Principles for Visualizing Knowledge and Information. *In:* Knowledge and Information Visualization, Springer-Verlag, Berlin, pp. 61-81

Dolinsky, J. U., Jenkinson, I. D., Colquhoun, G. J. 2007. Application of genetic programming to the calibration of industrial robots. *In:* Computers in Industry, 58, pp. 255-264

Duffy, A. H. B., Smith, J. S., Duffy, S. M. 1998. Design Reuse Research: a computational perspective – Keynote Paper. *In:* Design Reuse – Engineering Design Conference, Brunel University, UK

Edvinsson, L., Malone, M. S. 1997. Intellectual capital. New York, NY: HarperBusiness

Ericsson, A., Erixon, G. 1999. Controlling design variants: modular product platforms. ASME press, New York

Erixon, G. 1998. Modular Function Deployment – A Method for Product Modularization. Doctoral Thesis. Royal Institute of Technology (KTH), Stockholm

Gonzalez-Galvan, E. J., Loredo-Flores, A., Cervantes-Sanchez, J. J., Aguilera-Cortes, L. A., Skaar, S. B. 2008. An optimal path-generation algorithm for manufacturing of arbitrarily curved surfaces using calibrated vision. *In:* Robotics and Computer-Integrated Manufacturing, 24, pp. 77-91

Gultekin, H., Karasan, O. E., Akturk, M. S. 2009. Pure cycles in flexible robotic cells. *In:* Computers & Operations Research, 36, pp. 329-343

Haken, H. 1983 Synergetics, an Introduction: Nonequilibrium Phase Transitions and Self-Organization in Physics, Chemistry, and Biology, 3rd rev. enl. ed. New York: Springer-Verlag

Henderson, R., Clark, K. 1990. Architectural innovation: the reconfiguration of existing product technologies and the failure of establish firms. *In:* Administrative Science Quarterly, 35, pp. 9-30

Herman, I., Melancon, G., Marshall, M. S. 2000. Graph visualization and navigation in information visualization: A survey. *In:* IEEE Transactions on Visualization and Computer Graphics, 6, pp. 24-43

Hindreus, T. 2009. Synergy-Based Approach to Quality Assurance. Doctoral Thesis. Tallinn University of Technology, TUT Press, Tallinn

Hindreus, T., Kaljas, F., Martin, A., Tähemaa, T., Reedik, V. 2010. On synergy deployment in engineering design, *In:* DAAAM Baltic Conference, Tallinn University of Technology, Tallinn

Hindreus T., Reedik, V. 2006. Synergy-Based Approach to Engineering Design Quality. *In:* Proceedings of International Conference NordDesign 2006, University of Iceland, Reykjavik, pp. 158-168

Holley, C. D., Dansereau, D. F. 1984. The development of spatial learning strategies. *In:* Spatial learning strategies. Techniques, applications, and related issues. New York: Academic Press, pp. 3-19

Horin, B. P., Shoham, M. 2006. Singularity analysis of a class of parallel robots based on Grassmann-Cayley algebra. *In:* Mechanism and Machine Theory, 41, pp. 958-970

INCOSE. 2010. Systems Engineering Handbook, http://www.incose.org, 01.03.2010

Ishii, K., Yang, T. G. 2003. Modularity: international industry benchmarking and research roadmap. *In:* Proceedings of DETC`03, ASME 2003. ASME, USA

Ivancevic, V. G., Ivancevic, T. T. 2008. Complex Nonlinearity: Chaos, Phase Transitions, Topology Change and Path Integrals. Springer-Verlag

Jonassen, D. H. 1991. What are cognitive tools? *In:* cognitive Tools for learning, NATO ASI Series F, Computer and Systems Sciences, vol. 81, pp 1-6, Berlin/Heidelberg: Springer

Kaljas, F. 2005. Synergy-Based Approach to Design of the Interdisciplinary Systems. Doctoral Thesis on Mechanical and Instrumental Engineering E24. Theses of Tallinn University of Technology, TUT Press

Kevan, T. 2006. Shipboard machine monitoring for predictive maintenance. *In:* Wireless Sensors Magazine, Qestex, Q1

Kim, I., Son, J., Yarlagadda, P. 2003. A study on the quality improvement of robotic GMA welding process *In:* Robotics and Computer Integrated Manufacturing, 19, pp. 567-572

Krishnamurthy, L. et.al, 2005. Design and Deployment of Industrial Sensor Networks: Experiences from a Semiconductor Plant an the North Sea, ACM SenSys

Larkin, J. H., Simon, H. A. 1987. Why a diagram is (sometimes) worth 10000 words. *In:* Cognitive Science, 11, pp. 65-100

Le Grand, B., Soto, M. 1999. Navigation in huge information hierarchies, Application to network management. *In:* Proceedings ACM Workshop on New Paradigms in Information Visualization and Manipulation, pp. 55-61

Litzenberger, G. 2009. Executive summary of World Robotics. www.worldrobotics.org, 01.03.2010

Logie, R. H. 1995. Visio-spatial working memory. Hove: Lawrence Erlbaum Associates

Marshall, C. C. 2001. The haunting question of intelligibility. 11:th Hypertext, Aarhus, Denmark

Martin, A., Kaljas, F., Reedik, V. 2006. Synergy-Based Approach to Bad Engineering, *In:* Proceedings of the 8th Biennial Conference on Engineering Systems Design and Analysis, ASME Publications 1746CD, ESDA2006-95432

Matsi, B., Sarkans, M., Otto, T., Roosimölder, L. 2007. Method for Increasing Innovation Capacity in Development of Casing Type Details. *In:* Virtual and Rapid Manufacturing, Taylor & Francis, London, pp. 747-752

Mayer, R. E. 2001. Multimedia learning. Cambridge, UK, Cambridge University Press

Meyer, M. H., Lehnerd, A. P. 1997. The Power of Product Platforms: Building Value and Cost Leadership. The Free Press, New York

Mikhailov, A. S., Calenbuhr, V. 2002. From Cells to Societies: Models of Complex Coherent Action. Springer-Verlag

Neumann, A., Gräber, W., Tergan, S. O. 2005. ParIS – Visualizing Ideas and Information in a Resource-Based Learning Scenario. *In:* Knowledge and Information Visualization. Searching for Synergies. Springer-Verlag, Berlin

Otto, T., Aruväli, T., Serg, R., Preden, J. 2011. In process determining of the working mode in CNC turning. *In:* Estonian Journal of Engineering, vol. 17, 1, pp. 4-16

Pimmler, T. U., Eppinger, S. D. 1994. Integration Analysis of Product Decompositions. *In:* Proceedings of the ASME Sixth International Conference on Design Theory and Methodology, Minneapolis, USA, pp. 343-351

Plötzner, R., Lowe, R. 2004. Special issue: Dynamic visualizations and learning. *In:* Learning and Instruction, 14, pp. 235-357

Preden, J., Sarkans, M., Otto, T. 2007. Diagnostics of Machining and Assembly Systems by Networked Motes. *In:* Journal of Machine Engineering, 7(1-2), pp. 68-77

Rechtin, E. 1991. Systems Architecting: Creating & Building Complex Systems. Englewood Cliffs, NJ: P T. R Prentice Hall.

Reinertsen, D. G., Smith, P. G. 1992. Shortening the Product Development Cycle. *In:* Research-Technology Management, May-June

Roemer, T. A., Ahmadi, R., Wang, R. H. 2000. Time-cost trade-offs in overlapped product development. *In:* Operations Research, vol. 48, pp. 858-865

Safayeni, F. N., Derbentseva, A. J., Canas, A. 2005. A theoretical note on concepts and the need for cyclic concept maps. *In:* Journal of Research in Science Teaching

Sanches, R., Mahoney, J. 1997. Modularity, Flexibility and Knowledge Management in Product and Organization Design. *In:* IEEE Engineering Management Review (Winter), pp. 50-61

Sanderson, S., Uzumeri, M. 1995. Managing product families: the case of the Sony Walkman. *In:* Research Policy, 24, pp. 761-782

Sarkans, M., Roosimölder, L. 2004. Module reuse in product platform architecture. Machine tools and factories of the knowledge. (Banaszak Z., Pietrzyk M., Wieczorowski K., eds.). *In:* Machine Engineering, 4, pp. 45-51

Sarkans, M., Rokk, R., Roosimölder, L. 2004. Product platform modularization of luminaire light sources. *In:* Proceedings of NordDesign 2004. (Lehtonen T., Pulkkinen A., Riitahuhta A., eds.). TTY-Paino, pp.73-77

Scaife, M., Rogers, Y. 1996. External cognition: how do graphical representations work? *In:* Int. J. Human-Computer Studies, 45, pp. 185-213

Sebrechts, M. M. 2005. Visualizing Information in Virtual Space: Prospects and Pitfalls. *In:* Knowledge and Information, Knowledge and Information Visualization. Searching for Synergies. Springer-Verlag, Berlin

Siemens, G. 2005. Connectivism. A learning theory for the digital age. *In:*

International Journal of Instructional Technology and Distance Learning, 2(1), 3-10, (online: http://www.itdl.org/Journal/Jan_05/article01.htm)

Simon, H. A. 1996. The Sciences of the Artificial – 3rd Edition, Cambridge, Massachusetts, The MIT Press, 215 pages

SMErobot. 2010. European 6:th Framework called "SMErobot™", www.smerobot.org, 01.02.2010

Sreeram, R. T, Chawdry, P. 1998. A Design reuse model for collaborative product development process. *In:* Design Reuse – Engineering Design Conference, Brunel University, UK

Stake, R. B. 2000. Exploring commonality, product variety and the product structure – a mathematical approach. *In:* NordDesign 2000, pp. 205-214

Sterling, L. S., Taveter, K. 2009. The art of agent-oriented modeling. The MIT Press

Steward, D.V. 1981. The Design Structure System: A Method for Managing the Design of Complex Systems. *In:* IEEE Transactions on Engineering Management 28(3), pp. 71-74

Suh, N. P. 1990. Principles of Design. Oxford University Press, Cambridge, UK

Tergan, S. O. 2005. Digital Concept Maps for Managing Knowledge and Information. *In:* Knowledge and Information Visualization. Searching for Synergies. Springer-Verlag, Berlin

Tergan, S. O., Keller, T. 2005. Knowledge and Information Visualization. Searching for Synergies. Springer-Verlag Berlin, Heidelberg

Thompson, J. D. 1967. Organizations in action. New York, McGraw Hill

Tichem, M. 1997. Product structuring. An overview. *In:* Proceedings of the ICED`97, Tampere, Finland

Zachaaria, P. T., Aspragathos, N. A. 2005. Optimal robot task scheduling based on genetic algorithms. *In:* Robotics and Computer Integrated Manufacturing, 21, pp. 67-79

Ware, C. 2005. Visual Queries: The Foundation of Visual Thinking. *In:* Knowledge and Information Visualization. Searching for Synergies. Springer-Verlag, Berlin

Ware, C. 2004. Information Visualization: Perception for Design (2nd Edition). San Francisco, CA: Morgan Kaufman

Weideman, M., Kritzinger, W. 2003. Concept Mapping – a proposed theoretical model for implementation as a knowledge repository. Working paper from the "ICT in Higher Education" research project. University of Western Cape – South Africa

LIST OF PUBLICATIONS RELATED TO THESIS

The results of the research have been published in the following proceedings:

1. Sarkans, M., Eerme, M., **Programming Time Estimation and Production Planning Steps on Welding Robot Cells in SME-s.** In: Annals of DAAAM for 2011 & Proceedings of the 22nd International DAAAM Symposium, Vienna, 23-26 November 2011. (Editor) Katalinic, B., DAAAM International Vienna, pp. 1485 – 1486

ISBN: 978-3-901509-83-4

Abstract: Considering robot welding in small and medium-sized enterprises (SME), new challenges arise like programming of robots and production planning. Taking into consideration the needs of SMEs, a methodology for robot programming time calculation is introduced in this article. Also, the guidelines for production planning are given for different production quantities and products.

Written by M. Sarkans, supervised by Prof. M. Eerme.

2. Sarkans M., Roosimölder L., **Implementing of Robot Welding Cells Using Modular Approach.** In: Estonian Journal of Engineering, 16 (4), 2010, pp. 317 – 327

ISSN: 1736-6038

Web address: http://kirj.ee/public/Engineering/2010/issue_4/eng-2010-4-317-327.pdf

Referenced/indexed in: SciVerse Scopus

Abstract: It is shown that introducing robot welding cells in SMEs is a difficult task because of the limited resources and lack of the needed competence in SMEs. For successful realization of automation projects complex systems must be divided into smaller and simpler parts using the modular approach. The success of the project can be achieved through a suitable definition of the modules.

Written by M. Sarkans, supervised by Prof. L. Roosimölder.

3. Sarkans, M., Roosimölder, L., **Welding Robot Cell Implementation in SME-s Using Modular Approach - Case Study.** In: Proceedings of 7th International Conference of DAAAM Baltic Industrial Engineering, Tallinn, 22-24 April 2010. (Editor) Küttner, R.. Tallinn: Tallinn University of Technology Press, 2010, pp. 578 – 583

ISBN: 978-9985-59-982-2

Web address: http://innomet.ttu.ee/daaam/proceedings/PDF/Sarkans.pdf

Referenced/indexed in: ISI Web of Science

Abstract: The case study is based on the implementation of robot welding cells in several enterprises. Introducing robot welding cells in SMEs is quite a difficult task because of the extent of the project and lack of competencies in small companies. For the realization of such projects complex tasks must be divided into smaller and simpler targets using the modular approach.

Written by M. Sarkans, supervised by Prof. L. Roosimölder.

4. Preden, J., Sarkans, M., Otto, T., **Diagnostics of Machining and Assembly Systems by Networked Motes.** In: Machine Engineering, 7(1-2), 2007, pp. 68 - 77

ISSN: 1895-7595

Web address: https://www.etis.ee/ShowFile.aspx?FileVID=4507

Abstract: It is shown that the new technology has great potential in manufacturing systems, enabling the creation of an independent monitoring layer for the measurement of essential parameters like temperature, humidity, vibrations, movement, noise. The sensors are integrated into small sized boards and equipped with small sized accumulators. The modular approach is used to form a flexible product family of motes.

Written by J. Preden, M. Sarkans and T. Otto, supervised by Prof. L. Roosimölder.

5. Matsi, B., Otto, T., Sarkans, M., Roosimölder, L., **Method for Increasing Innovation Capacity in Development of Casing Type Details.** Bartolo, P. J. et al (Editor). In: Virtual and Rapid Manufacturing, Taylor & Francis, London, 2007, pp. 747 - 752

ISBN: 9780415416023

Web address: http://www.taylorandfrancis.com/books/details/ 9780415416023/

Referenced/indexed in: ISI Web of Knowledge, SciVerse Scopus

Abstract: Rapid prototyping (RP) is absorbed into practice and is being recognised as a significant technology for future product development. The paper investigates rapid product development made in collaboration with electronicians, designers and mechanical engineers for apparatus industry. The interaction of modularisation, collaborative engineering and competence merging methods in design phases are analysed.

Written mainly by B. Matsi with contributions from T. Otto and M. Sarkans, supervised by Prof. L. Roosimölder.

6. Sarkans, M., Preden, J., Otto, T., Reinson, T., **Smart dust based modular laboratory kit for monitoring workshop machinery.** In: Proceedings of 8th International Workshop on Research and Education in Mechatronics 2007. (Editor) Tamre, M., Tallinn: Tallinn University of Technology Press, 2007, pp. 299 - 308.

ISBN: 978-9985-59-707-1

Web address: https://www.etis.ee/ShowFile.aspx?FileVID=6496

Abstract: Laboratory works elaborated for teaching multidisciplinary subjects, such as Machine Automation or Computer Integrated Production Systems, grow obsolete rapidly, as modern CNC machine tools and robots are ‘smarter’ and contain more sensors. Updating the existing systems is expensive, one possible solution is to use motes or smart dust type sensor/communication systems. The paper introduces a modular design of a wireless sensor network for manufacturing systems.

Written mainly by T. Reinson and J. Preden with contributions from T. Otto and M. Sarkans, supervised by Prof. L. Roosimölder.

7. Sarkans, M., Roosimölder, L., Rokk, R., **Modularisation Information Carried by Products – Case Study.** In: Proceedings of the 5th International Conference of DAAAM Baltic: Industrial Engineering - Adding innovation capacity of labour force and enterpreneur, 20-22 April, Estonia, 2006, Tallinn: Tallinn University of Technology Press, 2006, pp. 77 - 80.

ISBN: 9985-894-92-8

Web address: http://innomet.ttu.ee/daaam06/proceedings/Design%20Engineering/17Sarkans.pdf

Referenced/indexed in: ISI Web of Science

Abstract: In the article modular products from product families are analysed. The products are a cellular phone test adapter and a luminary light source. They are analysed on different modularisation levels and in different PD process stages to gather information/knowledge about modularity. A model for modular knowledge management is proposed.

The initial material was provided by R. Rokk, the article was written by M. Sarkans and supervised by Prof. L. Roosimölder.

8. Sarkans, M., Otto, T., Roosimölder, L., **Modularization of e-courses Based on Monitoring of Skill Needs for Engineering Industry.** 10th International Symposium on Machine Design OST-2005, Stockholm, October 19-20, (Editor) Andersson, K., 2005, pp. 100 - 106.

Web address: http://www.md.kth.se/~kan/OST05/papers/paper_15.pdf

Peer-reviewed

Abstract: In the article the transition of conventional academic courses into knowledge and skills based courses is introduced. The proposed methodology is the most effective in the development of e-courses for the engineering sector, offering benefits not only in the development of study courses and curricula for educational institutions but also in the development of vocational training courses for the engineering industry.

Written by T. Otto and M. Sarkans, supervised by Prof. L. Roosimölder.

9. Sarkans, M., Roosimölder, L., **Module Reuse in Product Platform Architecture.** In: Machine Engineering, 4 (1-2), 2004, pp. 45 - 51.

ISSN: 1642-6568

Web address: https://www.etis.ee/ShowFile.aspx?FileVID=4177

Abstract: By reusing already designed products sharing a common platform as a basis for new ones, the scale of economy can be achieved and products can be effectively differentiated in the eyes of a customer. The creation of a product platform for test adapters by reusing modules is discussed in the paper. Not all modules could be reused for the development of new products, the appropriate ones should be selected. The methodology for this should be suggested. 36 test adapters which share a common product platform were under investigation. Functions and parameters for the required modules were defined.

Written by M. Sarkans, supervised by Prof. L. Roosimölder.

10. Sarkans, M., Rokk, R., Roosimölder, L., **Product Platform Modularisation of Luminaire Light Sources.** In: Proceedings of Norddesign 2004 - Product Development in Changing Environment: NordDesign 2004 Conference, 18-20 August, Tampere, Finland, Tampere University of Technology, 2004, pp. 73 - 77.

ISBN: 978-952-15-1227-8

Web address: https://www.etis.ee/ShowFile.aspx?FileVID=4180

Abstract: Product platform modularisation and formation for luminaire light sources are described and analyzed in the paper. Such a platform would reduce lead-time and speed up the manufacture of new products. The creation of the product platform was started by analyzing functional structures of all luminaire light sources produced in the company.

The initial material was provided by R. Rokk, the article was written by M. Sarkans and supervised by Prof. L. Roosimölder.

11. Sarkans, M., Roosimölder, L., **Product Platform Modularization for Test Adapter.** In: 8th International Symposium on Machine Design OST-2003, Oulu, June 5-6, 2003, Oulun Yliopisto Konetekniikan Osasto, 2003, pp. 100 - 106.

ISBN: 951-42-7215-3

Web address: https://www.etis.ee/ShowFile.aspx?FileVID=4181

Peer-reviewed

Abstract: By its nature, testing equipment is product-specific. Consumer electronics products often form product families. As testable parameters within a product family are largely overlapping, opportunities for creating a modular testing platform should be explored. Such a platform would reduce lead-time and speed up the manufacture of test equipment for new electronic products.

Written by M. Sarkans, supervised by Prof. L. Roosimölder.

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3. Education

Educational institution	Graduation year	Education (field of study/degree)
Tallinn University of Technology	2003	Product Development and Production Engineering/M.Sc.
TTK University of Applied Sciences	2000	Mechanical Engineering/Diploma of Professional Higher Education (*Cum Laude*)
Tallinn Secondary School No 13	1996	Secondary education

4. Language competence/skills

Language	Level
Estonian	Mother tongue
English	Advanced
Finnish	Intermediate
Russian	Intermediate

5. Special Courses

Period	Educational or other organisation
10/2007	ABB Ltd Finland, R102W, IRC5 Basic Programming Course, Arc Welding
09/2008	ABB Ltd Finland, R104, IRC5 Advanced Programming Course, Force Control Options

6. Professional Employment

Period	Organisation	Position
02/2009 – up to the present	Tallinn University of Technology	Educational Technology Officer
10/2011 – up to the present	IMECC Ltd	Project Manager

09/2007 – up to the present	Norcar-BSB Eesti Ltd	Engineer
2006 – 2007	Tallinn University of Technology	Lecturer
2001 – 2006	Tallinn University of Technology	Assistant
2001 – 2002	DPS Automaatika Ltd	Designer
1999 – 2001	JOT Eesti Ltd	Designer, FMEA specialist
1998 – 1999	Tigma Ltd	IT specialist, consultant
1998 – 1999	TTK University of Applied Sciences	Laboratory technician
1997 – 1998	Ratas Ltd	Trainee, operator

7. Scientific work:
Martins Sarkans, Master's Degree, 2003, supervisor Lembit Roosimölder, Testadapter product platform modulararisation for JOT Eesti Ltd, Tallinn University of Technology

8. Supervised theses:

Development project for electro-pneumatic training stand	2006	TUT, M.Sc., Aivar Auväärt
Development of RFID Tag Reader	2006	TUT, M.Sc., Birthe Matsi
Development of RFID Tag Reader	2006	TUT, M.Sc., Triin Toon
Manufacture preparation of lifting boom bases in Finmec Ltd	2006	TUT, M.Sc., Madis Kaup
Product development process and implementation of new products in Glamox, based on product C50	2009	TUT, M.Sc., Raido Rokk
Methodology for changes management for plastic injection moulds manufacturing. Case study - Keylocker	2009	TUT, M.Sc., Virgo Oeselg

9. Main areas of scientific work/Current research topics:
4. Natural Sciences and Engineering, 4.13. Mechanical Engineering, Automation Technology and Manufacturing Technology (Modularization. Modularized products. Modularization in Product Development Process)

10. Other research projects:
Mechatronic and Production Systems Proactivity and Behavioural Models;
e-Manufacturing Concept for SME.

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3. Hariduskäik

Õppeasutus (nimetus lõpetamise ajal)	Lõpetamise aeg	Haridus (eriala/kraad)
Tallinna Tehnikaülikool	2003	Tootearendus ja tootmis-tehnika/tehnikateaduste magister
Tallinna Tehnikakõrgkool	2000	Masinaehitus/rakenduslik kõrgharidus (*Cum Laude*)
Tallinna 13. Keskkool	1996	Keskharidus

4. Keelteoskus

Keel	Tase
Eesti keel	Emakeel
Inglise keel	Kõrgtase
Soome keel	Kesktase
Vene keel	Kesktase

5. Täiendusõpe

Õppimise aeg	Täiendusõppe läbiviija nimetus
10.2007	ABB OY Finland, R102W, IRC5 programmeerimise baaskoolitus, kaarkeevitus
09.2008	ABB OY Finland, R104, IRC programmeerimise jätkukoolitus, Force Control võimalused

6. Teenistuskäik

Töötamise aeg	Tööandja nimetus	Ametikoht
02.2009 – tänaseni	Tallinna Tehnikaülikool	Haridustehnoloog
10.2011 – tänaseni	IMECC OÜ	Projektijuht
09.2007 – tänaseni	Norcar-BSB Eesti AS	Insener
2006 – 2007	Tallinna Tehnikaülikool	Lektor
2001 – 2006	Tallinna Tehnikaülikool	Assistent
2001 – 2002	DPS Automaatika OÜ	Konstrueerija

1999 – 2001	JOT Eesti OÜ	Konstrueerija, FMEA spetsialist
1998 – 1999	Tigma AS	Arvutispetsialist, konsultant
1998 – 1999	Tallinna Tehnikakõrgkool	Laboritehnik
1997 – 1998	Ratas OÜ	Pingioperaator

7. Teadustegevus:
Martinš Sarkans, magistrikraad (teaduskraad), 2003, juhendaja Lembit Roosimölder, Testadapteri tooteplatvormi moodulsüsteemi arendus OÜ JOT Eesti, Tallinna Tehnikaülikool

8. Juhendatud lõputööd:

Teema	Aasta	Institutsioon/kraad/nimi
Elektropneumaatilise õppestendi arendusprojekt	2006	Tallinna Tehnikaülikool, M.Sc., Aivar Auväärt
RFID lugeja korpuse väljatöötamine	2006	Tallinna Tehnikaülikool, M.Sc., Birthe Matsi
RFID lugeja korpuse väljatöötamine	2006	Tallinna Tehnikaülikool, M.Sc., Triin Toon
Tõstepoomi alusraamide tootmise ettevalmistus AS-is Finmec	2006	Tallinna Tehnikaülikool, M.Sc., Madis Kaup
Tootearendusprotsess ja uute toodete juurutamine Glamox baasil, C50 toote näitel	2009	Tallinna Tehnikaülikool, M.Sc., Raido Rokk
Plastisurvevaluvormi muudatuste läbiviimise metoodika - võtmelaeka koostu näitel	2009	Tallinna Tehnikaülikool, M.Sc., Virgo Oeselg

9. Teadustöö põhisuunad:
4. Loodusteadused ja tehnika, 4.13. Mehhanotehnika, automaatika, tööstustehnoloogia (Modulariseerimine. Modulariseeritud tooted. Modulariseerimine tootearendusprotsessis.)

10. Teised uurimisprojektid:
Mehhatroonika- ja tootmissüsteemide proaktiivsus ja käitumismudelid; E-tootmise kontseptsioon väike- ja keskmise suurusega ettevõtetele.

DISSERTATIONS DEFENDED AT TALLINN UNIVERSITY OF TECHNOLOGY ON *MECHANICAL AND INSTRUMENTAL ENGINEERING*

1. **Jakob Kübarsepp**. Steel-Bonded Hardmetals. 1992.

2. **Jakub Kõo**. Determination of Residual Stresses in Coatings &Coated Parts. 1994.

3. **Mart Tamre**. Tribocharacteristics of Journal Bearings Unlocated Axis. 1995.

4. **Paul Kallas**. Abrasive Erosion of Powder Materials. 1996.

5. **Jüri Pirso**. Titanium and Chromium Carbide Based Cermets. 1996.

6. **Heinrich Reshetnyak**. Hard Metals Serviceability in Sheet Metal Forming Operations. 1996.

7. **Arvi Kruusing**. Magnetic Microdevices and Their Fabrication methods. 1997.

8. **Roberto Carmona Davila**. Some Contributions to the Quality Control in Motor Car Industry. 1999.

9. **Harri Annuka**. Characterization and Application of TiC-Based Iron Alloys Bonded Cermets. 1999.

10. **Irina Hussainova**. Investigation of Particle-Wall Collision and Erosion Prediction. 1999.

11. **Edi Kulderknup**. Reliability and Uncertainty of Quality Measurement. 2000.

12. **Vitali Podgurski**. Laser Ablation and Thermal Evaporation of Thin Films and Structures. 2001.

13. **Igor Penkov**. Strength Investigation of Threaded Joints Under Static and Dynamic Loading. 2001.

14. **Martin Eerme**. Structural Modelling of Engineering Products and Realisation of Computer-Based Environment for Product Development. 2001.

15. **Toivo Tähemaa**. Assurance of Synergy and Competitive Dependability at Non-Safety-Critical Mechatronics Systems design. 2002.

16. **Jüri Resev**. Virtual Differential as Torque Distribution Control Unit in Automotive Propulsion Systems. 2002.

17. **Toomas Pihl**. Powder Coatings for Abrasive Wear. 2002.

18. **Sergei Letunovitš**. Tribology of Fine-Grained Cermets. 2003.

19. **Tatyana Karaulova**. Development of the Modelling Tool for the Analysis of the Production Process and its Entities for the SME. 2004.

20. **Grigori Nekrassov**. Development of an Intelligent Integrated Environment for Computer. 2004.

21. **Sergei Zimakov**. Novel Wear Resistant WC-Based Thermal Sprayed Coatings. 2004.

22. **Irina Preis**. Fatigue Performance and Mechanical Reliability of Cemented Carbides. 2004.

23. **Medhat Hussainov**. Effect of Solid Particles on Turbulence of Gas in Two-Phase Flows. 2005.

24. **Frid Kaljas**. Synergy-Based Approach to Design of the Interdisciplinary Systems. 2005.

25. **Dmitri Neshumayev**. Experimental and Numerical Investigation of Combined Heat Transfer Enhancement Technique in Gas-Heated Channels. 2005.

26. **Renno Veinthal**. Characterization and Modelling of Erosion Wear of Powder Composite Materials and Coatings. 2005.

27. **Sergei Tisler**. Deposition of Solid Particles from Aerosol Flow in Laminar Flat-Plate Boundary Layer. 2006.

28. **Tauno Otto**. Models for Monitoring of Technological Processes and Production Systems. 2006.

29. **Maksim Antonov**. Assessment of Cermets Performance in Aggressive Media. 2006.

30. **Tatjana Barashkova**. Research of the Effect of Correlation at the Measurement of Alternating Voltage. 2006.

31. **Jaan Kers**. Recycling of Composite Plastics. 2006.

32. **Raivo Sell**. Model Based Mechatronic Systems Modeling Methodology in Conceptual Design Stage. 2007.

33. **Hans Rämmal**. Experimental Methods for Sound Propagation Studies in Automotive Duct Systems. 2007.

34. **Meelis Pohlak**. Rapid Prototyping of Sheet Metal Components with Incremental Sheet Forming Technology. 2007.

35. **Priidu Peetsalu**. Microstructural Aspects of Thermal Sprayed WC-Co Coatings and Ni-Cr Coated Steels. 2007.

36. **Lauri Kollo**. Sinter/HIP Technology of TiC-Based Cermets. 2007.

37. **Andrei Dedov**. Assessment of Metal Condition and Remaining Life of In-service Power Plant Components Operating at High Temperature. 2007.

38. **Fjodor Sergejev**. Investigation of the Fatigue Mechanics Aspects of PM Hardmetals and Cermets. 2007.

39. **Eduard Ševtšenko**. Intelligent Decision Support System for the Network of Collaborative SME-s. 2007.

40. **Rünno Lumiste**. Networks and Innovation in Machinery and Electronics Industry and Enterprises (Estonian Case Studies). 2008.

41. **Kristo Karjust**. Integrated Product Development and Production Technology of Large Composite Plastic Products. 2008.

42. **Mart Saarna**. Fatigue Characteristics of PM Steels. 2008.

43. **Eduard Kimmari**. Exothermically Synthesized B_4C-Al Composites for Dry Sliding. 2008.

44. **Indrek Abiline**. Calibration Methods of Coating Thickness Gauges. 2008.

45. **Tiit Hindreus**. Synergy-Based Approach to Quality Assurance. 2009.

46. **Karl Raba**. Uncertainty Focused Product Improvement Models. 2009.

47. **Riho Tarbe**. Abrasive Impact Wear: Tester, Wear and Grindability Studies. 2009.

48. **Kristjan Juhani**. Reactive Sintered Chromium and Titanium Carbide-Based Cermets. 2009.

49. **Nadežda Dementjeva**. Energy Planning Model Analysis and Their Adaptability for Estonian Energy Sector. 2009.

50. **Igor Krupenski**. Numerical Simulation of Two-Phase Turbulent Flows in Ash Circulating Fluidized Bed. 2010.

51. **Aleksandr Hlebnikov**. The Analysis of Efficiency and Optimization of District Heating Networks in Estonia. 2010.

52. **Andres Petritšenko**. Vibration of Ladder Frames. 2010.

53. **Renee Joost**. Novel Methods for Hardmetal Production and Recycling. 2010.

54. **Andre Gregor**. Hard PVD Coatings for Tooling. 2010.

55. **Tõnu Roosaar**. Wear Performance of WC- and TiC-Based Ceramic-Metallic Composites. 2010.

56. **Alina Sivitski**. Sliding Wear of PVD Hard Coatings: Fatigue and Measurement Aspects. 2010.

57. **Sergei Kramanenko**. Fractal Approach for Multiple Project Management in Manufacturing Enterprises. 2010.

58. **Eduard Latõsov**. Model for the Analysis of Combined Heat and Power Production. 2011.

59. **Jürgen Riim**. Calibration Methods of Coating Thickness Standards. 2011.

60. **Andrei Surzhenkov**. Duplex Treatment of Steel Surface. 2011.

61. **Steffen Dahms**. Diffusion Welding of Different Materials. 2011.

62. **Birthe Matsi**. Research of Innovation Capasity Monitoring Methodology for Engineering Industry. 2011.

63. **Peeter Ross**. Data Sharing and Shared Workflow in Medical Imaging. 2011.

64. **Siim Link**. Reactivity of Woody and Herbaceous Biomass Chars. 2011.

65. **Kristjan Plamus**. The Impact of Oil Shale Calorific Value on CFB Boiler Thermal Efficiency and Environment. 2012.

66. **Aleksei Tšinjan**. Performance of Tool Materials in Blanking. 2012.