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Research of Innovation Capacity Monitoring Methodology for Engineering Industry

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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 E62

Innovatsioonivõimekuse monitooringu metoodika töötlevale tööstusele

BIRTHE MATSI

TTÜ KIRJASTUS

CONTENTS

INTRODUCTION

Running new product development effectively requires wise decisions. It is not important to monitor only profitability and cash flow. In addition, it is necessary to understand and monitor also the key drivers of business, since the driver has a major impact on the performance of the business.

Already in 1990s it was noted that KPIs (Key Performance Indicators) provide the reality of implementing performance measurement in an organization [Kaplan, Norton, 1996]. KPIs can be used for all types of project management: IT (information technology), construction, engineering, risk management, supply chain, safety, quality, manufacturing, financial management, sales etc [Parmenter, 2007]. It has been suggested that in today's competitive and global financial crisis environments, organizations need to be masters of anticipating customers' needs, devising radical new product and service offerings, and rapidly deploying new production technologies into operating and service delivery processes. For several decades, performance measurement has been used as an internal informational tool to evaluate business units operations, and make program and budgetary decisions based on financial and non-financial KPIs. These widely known KPIs (return on investment, earnings per share, revenue growth, profit margin, time-to-market of new products/services, research and development activities spend as percentage of revenue etc.) are not the main indicators that should be taken into account for achieving organization goals more effectively. There are some additional key drivers that should be handled in product development and innovation. In other words, it is evident that it is important to define KPIs that represent a set of measures focusing on those aspects of organizational performance that are the most critical for success of the organization [Kaplan, Norton, 2004]. Therefore it is important to research other issues that could help to achieve higher innovation capacity in enterprises. For that reason other key-drivers should be taken into account for minimizing product development failure risks and make the whole development process more effective.

Additional factors that can be handled for monitoring enterprises innovation capacity have been investigated in the current study. Based on „better-practice" approach different real product development case studies have been handled and investigated. New directions in rapid prototyping, concurrent engineering, innovation capacity estimation and data management have been found. All these play an important role as key performance criteria that enable to minimize development project risks and achieve better results. Therefore, the study has been conducted by establishing three main starting-points or problems that have been taken into account for proposing additional key-drivers in innovation and new product development for achieving innovation capacity in enterprises.

Firstly, the research has been done from rapid prototyping (RP) point of view. Prototyping a product is a very critical issue and in addition to prototyping speed, it is dependent on many other factors such as cost trade-off, accuracy of prototyped part, material property, part size, part strength and availability. A lot has been written about different rapid prototyping methods and their histories but it is remarkable how the question of accuracy in most successful case studies has been carefully avoided. Thus "bottlenecks" in rapid prototyping have been analyzed in more detail and suggestions regarding elimination of these problems have been proposed.

Secondly, KPIs in innovation have been measured mainly by taking into account the following: the percentage of ideas receiving positive evaluation from teams, the number of prototypes and test products in production or the average time from idea evaluation to full implementation. Besides KPIs, innovation from organization competences point of view has to be handled. The influence of innovation to productivity has been so far investigated mainly from the viewpoint of economical science. But the innovation capacity can be viewed also from the point of view of the competences of employee. Employees and entrepreneurs in the machinery, metal and apparatus engineering sector are dependent on competency, which influences technological capacity. In Estonia we have over 400 small and medium sized enterprises in the machinery, apparatus and metal engineering sector. In most cases the "bottleneck" is missing methodology for analysis of potential effect of implementation novel technologies/products. Therefore the enterprises are not very flexible for acceptance and enforcement of new technological resources or production range. Thus, innovation capacity of employees and entrepreneurs in the machinery, metal and apparatus engineering sector in Estonia, has been analyzed and mapped, web-based expert tool for providing recommendations regarding product development and elaboration of development models for the engineering industry sector have been made.

Thirdly, as during the enterprise competences mapping a big amount of data was gathered it was necessary to analyze it and find a suitable data management method. Data mining is nowadays applied mostly in the industries of finance, insurance, telecommunications and retail, which have provided examples of investigations from great quantity of data. Therefore, it was important to investigate data management possibilities from new aspects and find out how data mining implementation also in manufacturing area could help to achieve more effective results in business. On the other hand, it was viewed how data management based on local data warehouse could help to achieve better results in business and customer satisfaction field. Hereby, key performance criteria from data management implementation possibilities have been analyzed and other new possibilities for e-solutions were investigated and implemented.

Taking into account all findings and results from handled real rapid prototyping, innovation estimation and data management case studies, it has been possible to point out additional key performance criteria for innovation and product development assessment and help to understand how these could also add the value for increasing customer satisfaction. The current research provides not only surplus values for all SME-s, who deal with product development and are interested in development team's higher innovation capacity, but also describes and points out how customer satisfaction can be improved by using new data management possibilities in e-business. Therefore, current research that is based on Estonian enterprises best-practice approach provides methodology for innovation capacity monitoring that enables to improve innovation capacity in these enterprises.

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ABBREVIATIONS AND SYMBOLS

ANSYS	engineering simulation software
BAM	Business Activity Monitoring
BST	Breakaway Support Technology
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering
CAM	Computer-Aided Manufacturing
CASE	Computer-Aided Software Engineering
CE	Concurrent Engineering
CRISP-DM	Cross Industry Standard Process for Data Mining
DM	Data Mining
DMP	Data Mining Process
DRM	Digital Rights Management
EBM	Electron Beam Melting
EDIF	Electronic Design Interchange Format
ELIKO	name of Competence Centre in Electronics-, Info- and Communication Technologies
EPS	Earnings Per Share
ERP	Enterprise Research Planning
ESPRIT	European Strategic program on Research in Information Technology of the European Union
FDM	Fused Deposition Modeling
FEA	Finite Element Analysis
FMECA	Failure Mode, Effects, and Criticality Analysis
IDA	Institute for Defense Analysis
IPD	Integrated Product Development
IPT	Inkjet Printing Technology
IS	Information System
IT	Information Technology
JIT	Just In Time
KD	Knowledge Discovery
KDD	Knowledge Discovery in Databases
KPI	Key Performance Indicator
LOM	Laminated Object Manufacturing
MRP	Material Requirements Planning
NPD	New Product Development
NP	New Product
OECD	Organization for Economic Co-operation and Development
PC	Personal Computer
PCA	Post-Curing Apparatus
PCB	Printed Circuit Board

PD	Product Development
PDP	Product Development Process
PLST	Plastic Laser Sintering Technology
PMS	Performance Measurement System
RFID	Radio Frequency Identification
ROI	Return on Investments
RP	Rapid Prototyping
R&D	Research and Development
RM	Rapid Manufacturing
SLA	Stereo Lithography
SLS	Selective Laser Sintering
SME	Small and Medium sized Enterprises
SST	Soluble Support Technology
STL	Stereo Lithography Tessellation Language
STEP	Standard for the Exchange of Product model data
TQM	Total Quality Management
VP	Virtual Prototyping
WYSIWYG	What You See Is What You Get
3DP	Three Dimensional Printing

Symbol	Unit	Comment
A_{pf}	EEK	amortization of machine for preparative and finishing steps
A_{build}	EEK	amortization of building part
C_{build}	EEK	part(-s) building costs
$C_{comp.\ air}$	EEK	cost of compressed air
$C_{electr.}$	EEK	cost of electricity
$C_{mat.\text{-}build}$	EEK	material cost in building step
$C_{mat.\text{-}pf}$	EEK	material costs in preparative and finishing steps
C_{pf}	EEK	preparative and finishing costs
C_T	EEK	total costs of the part manufactured with PLST
$C_{t\text{-}unit}$	EEK/s	cost per time-unit
$C_{w\text{-}unit}$	EEK/g	cost per unit of weight
l	mm	height of the part
n_i		number of measurands
$s^2(x_{ij})$		estimate of the variance
$s(x_{ij})$		experimental standard deviation
$s(\bar{x}_i)$		standard uncertainty of measurement
t_{heat}	s	heating time
t_{layer}	s	layer building time
t_{lower}	s	time to spread the lower material layer
t_{upper}	s	time to spread the upper material layer

$u_{instrument}$		uncertainty component of measurement device
$u(y)$		uncertainty of measurement
V_{layers}	mm^3	lower and upper material-layer volume
$\bar{x}_i$		arithmetic mean
x_{ij}		weighting factors
σ^2		the variance of arithmetic means
ρ_{powder}	g/cm^3	density of powder

1 OVERVIEW OF LITERATURE

This chapter gives an overview about the literature related to the current study. Therefore the main terms together with the main overviews that have been involved in the current study are presented in the following sub-chapters. On the other hand, this chapter helps to understand the second part of the work more clearly where the main objectives and tasks together with results will be discussed and pointed out in chapters 2, 3, 4, 5 and 6.

1.1 Key Performance Indicators in New Product Development and Innovation

A performance indicator or key performance indicator (KPI) is a measure of performance. KPIs are commonly used to help an organization define and evaluate how successful its business is. The act of monitoring KPIs in real-time is known as business activity monitoring (BAM). Many things are measurable. That does not make them as a key to the organization's success. In selecting KPIs it is critical to limit them to those factors that are essential to the organization goals. Therefore it can be said, that KPIs are indicators that help to evaluate the progress of an organization towards its vision and long-term goals, especially toward difficult to quantify knowledge-based goals.

Based on PMS (Performance Measurement System) literature, performance can be classified into two major groups: financial and non-financial. Financial measures may include return on investment (ROI), earnings per share (EPS), revenue (sales) growth, profit margin etc. Non-financial measures may include customer satisfaction, employee satisfaction, production efficiency, quality, customer service etc [Moll, Hoque, 2008]. Thus KPIs are frequently used to "value" difficult to measure activities such as the benefits of leadership development, engagement, service, and satisfaction. KPIs are typically tied to an organization's strategy using concepts or techniques. It should be taken into account that KPIs differ depending on the nature and strategy of the organization. Therefore specific indicators in product development can be as follows:

- Time-to-market of new products/services. The time it takes from the time a product is envisioned or defined until it is on store shelves.
- Research and development activities spend as percentage of revenue.
- Percentage of sales from products launched previous year.
- From innovation point of view these KPI-s could typically include:
    - the number of ideas put forward by individuals to team leaders;
    - the percentage of ideas receiving positive evaluation from teams;

- the proportion of positive ideas receiving resource allocation;
- resources made available for continuous innovation;
- the number of prototypes and test products going into full production;
- the average time from idea evaluation to full implementation;
- savings achieved through successful operational efficiency ideas;
- revenue generated through ideas resulting in new products or services [Wood, 2005].

These specific indicators for product development and innovation assessment are important key-drivers, but there are some additional important factors that should be taken into account for minimizing product development project failure risks and making the whole product development process more effective. For that reason it is important to research additional key-drivers based on best practice approach and find how innovation capacity can be monitored in enterprises and how its implementation could lead to better business.

1.2 Innovation and New Product Development

Innovation is a complex concept as there are a number of forms of innovation. The general definition is presented here followed by narrower definitions. Innovation in its widest sense is considered to be anything that is new to a business. The traditional concept of innovation is well documented and defined. In fact, it has been defined particularly for technological innovation to a degree that survey questions have been standardized in the OECD´s Oslo Manual (OECD´s Oslo Manual, 1997), which states, „technological innovations comprise new products and processes and significant technological changes of products and processes. An innovation has been implemented if it is introduced on the market (product innovation) or used within a production process (process innovation)“ [Hine, Kapeleris, 2006].

Innovation plays an important role in organization and economic development, as evidenced by the large scope and sum of literature. It can be found in areas like management, learning, strategy, clusters and networks. Furthermore, innovation has been studied from many disciplinary approaches, including economics, sociology, marketing and management, geography and organizational level. Distinctions can be made mainly between: „Technological and non-technological innovation“ and „Product and process innovation“.

Innovation is the lifeblood of any organization. It is therefore important to have a good working innovation definition. Innovation can apply to many things. It is usually the term applied to a new product but it can be used also to describe new processes, methods or inventions. The following are four essential parts to a definition of innovation: something new, better than what already exists, economically viable and widespread appeal.

1.2.1 History of Innovation

Innovation has long been argued to be the engine of growth [Trott, 2005]. Innovation has been a topic of discussion and debate for hundreds of years. The 19th century economic historians observed that the acceleration in economic growth was the result of technological progress. However, little effort was directed towards understanding, how changes in technology contributed to this growth. Schumpeter was the first economist to emphasize the importance of a new product as stimulus to economic growth [Schumpeter, 1934]. He argued that the competition posed by new products was far more important than marginal changes in the prices of existing products. Early observations suggested that economic development does not occur in any regular manner but seemed to occur in waves of activity, thereby indicating the important influence of external factors on economic development. This macro view of innovation as cyclical can be traced back to the mid-nineteenth century. Marx was the first to suggest that innovations could be associated with waves of economic growth. Since then others such as Schumpeter, Kondratieff, Abernathy and Utterback have argued the long-wave theory of innovation. It is known that Stalin imprisoned Kondratieff for his views on economic growth theories because they conflicted with those of Marx. Marx suggested that capitalist economies would eventually decline, whereas Kondratieff argued that they would experience waves of growth and decline. Abernathy and Utterback contended that at the birth of any industrial sector there is radical product innovation which is then followed by radical innovation in production processes, followed, in turn, by widespread incremental innovation [Abernathy, Utterback, 1978]. This standpoint was once popular and seemed to reflect the life cycles of many industries. It has, however, failed to offer any understanding of how to achieve innovative success.

After the Second World War economists began to take an even greater interest in innovation. One of the most important influences on innovation seemed to be industrial research and development. There was a need to understand how science and technology affected the economic system. At that time firms behaved differently and this led to the development of a new theoretical framework that attempted to understand how firms managed and why some firms appeared to be more successful than others. Hence, later in 1960s, the new framework placed more emphasis on the firm and its internal activities. The firm and how it used its resources was as the key influence on innovation. There exists an understanding that innovation process includes an economic perspective, a business management strategy perspective and organizational behavior with an attempt to look at internal activities. It was recognized that firms in relationship with other firms and trade, compete and cooperate with each other. It was recognized that the activities of individuals within the firm also affect process of innovation.

In the 20th century Schumpeter argued that modern firms equipped with R&D laboratories have become the central innovative actors. Success in the future as in the past will lie in the ability to acquire and utilize knowledge and apply this to the development of a new product. Uncovering, how to do this remains one of today's most difficult management problem.

The importance of uncovering and satisfying the needs of customers is the important role played by marketing and these activities feed into the new product development process. Recent studies by Hamel and Prahalad and Christensen suggest that listening to one's customer may actually stifle technological innovation and be detrimental to long-term business success.

1.2.2 Types of Innovation

Industrial innovation does not include only major (radical) innovations, but also minor (incremental) technological advances. Indeed, the definition offered above suggests that successful commercialization of the innovation may involve considerably wider organizational changes. But technological innovation can be accompanied by additional managerial and organizational changes, often referred to as innovations. This presents a far more blurred picture and begins to widen the definition of innovation to include virtually any organizational or managerial change. Table 1.1 shows the typology of innovations [Trott, 2005].

Table 1.1 Typology of innovations

Type of innovation	**Example**
Product innovation	The development of a new or improved product.
Process innovation	The development of a new manufacturing process.
Organizational innovation	A new venture division; a new internal communication system; introduction of a new accounting procedure.
Management innovation	TQM system.
Production innovation	Quality circles, JIT manufacturing system, new production planning software, e.g. MRP II, new inspection system.
Commercial/marketing innovation	New financing arrangements; new sales approach, e.g. direct marketing.
Service innovation	Internet-based financial services.

1.2.3 Models of Innovation

Over the past ten years the literature on what drives innovation has reflected the ideas of two different schools: the market-based view and the resource-based view. According to the market-based view market conditions provide the context, which facilitates or constrains the extent of firm innovation activity. The key issue here is the ability of firms to recognize opportunities in the market place.

According to the resource-based view of innovation a market-driven orientation does not provide a secure foundation for formulating innovation strategies for markets, which are dynamic and volatile. Instead, a firm's own resources provide a much more stable context in which to develop its innovation activity and shape its markets according to its own view. The resource-based view of innovation focuses on the firm and its resources, capabilities and skills. Technology-driven model is also known as technology-push model, where it is assumed that scientists make unexpected discoveries, technologists apply them to develop product ideas and engineers and designers turn them into prototypes for testing. Marketing and sales only promote the product to potential customers. Therefore, in this model the marketplace is a passive recipient for the fruits of R&D. This technology-push model dominated after the Second World War. It was not until the 1970s that new studies of actual innovations suggested that the role of the marketplace was influential in the innovation process [Hippel, 1978]. This led to the second linear model, market-pull model of innovation. The customer need-driven model emphasizes the role of marketing as an initiator of new ideas resulting from close interactions with customers. These, in turn, are conveyed to R&D for design and engineering and then to manufacturing for production. Linear models of innovation are presented on Figure 1.1.

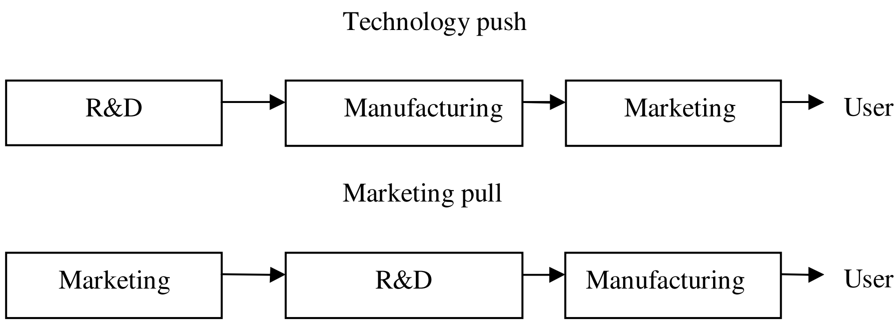


Figure 1.1 Linear models of innovation

The linear model is only able to offer an explanation of where the initial stimulus for innovation was born, that is where the trigger for the idea or need was initiated. The simultaneous coupling model shown on Figure 1.2 suggests that it is the result of simultaneous coupling of knowledge within all tree functions that foster innovation.

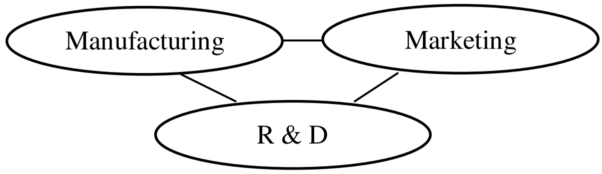


Figure 1.2 Model of simultaneous coupling innovation

The interactive model develops this idea further and links together the technology-push and market-pull models (see Figure 1.3). It emphasizes that innovations occur as the result of the interaction of the marketplace, the science base and the organization's capabilities. Like the coupling model, there is no explicit starting point. The use of information flows is used to explain how innovations transpire and that they can arise from a wide variety of points.

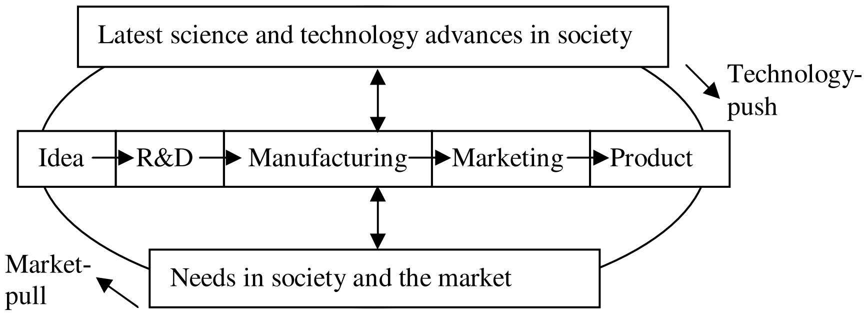


Figure 1.3 Interactive model of innovation

In the centre of the model there are organizational functions of R&D, engineering and design, manufacturing and marketing and sales. While at first this may appear to be a linear model, the flow of communication is not necessarily linear. There is a provision for feedback. Also, linkages with the science base and the marketplace occur between all functions, not just with R&D or marketing. For example, it may be the manufacturing function which initiates a design improvement that leads to the introduction of either a different material or the eventual development by R&D of a new material. Finally, the generation of ideas is shown to be dependent on inputs from three basic components: organization capabilities, the needs of the market, the science and technology base. Table 1.2 summarizes the historical development of the dominant models of the industrial innovation process [Rothwell, 1992].

Table 1.2 Chronological developments of innovation models

Date	Model	Characteristics
1950/60s	Technology push	Simple linear sequential process; emphasis on R&D; the market is a recipient of the fruits of R&D.
1970s	Market pull	Simple linear sequential process; emphasis on marketing; the market is the source for directing R&D; R&D has a reactive role.
1980s	Coupling model	Emphasis on integrating R&D and marketing.
1980/90s	Interactive model	Combinations of push and pull.
2000s	Network model	Emphasis on knowledge accumulation and external linkages.

1.2.4 Opportunities Provided by the 21st Century

To paraphrase Charles Dickens, for innovation in the new century, it is the best of times. Industrial technology widens people's understanding of the world at an accelerating rate. In the oldest industry in the world, agriculture, companies learn to use genetic and genomic technology to make crops more resistant to pests, droughts and diseases, even as they produce more output per acre. In contemporary industry, retail, achievements in computing and communication bring retailers into closer contact with their customers as well as their suppliers, enabling them to provide more variety with fewer inventories than ever before. The burgeoning services businesses all benefit from technologies that offer better communication with more capabilities at lower prices. The largest service industry, health care is experiencing an explosion in our scientific understanding of the forces that create life, with the result being the prospect of longer, healthier lives for us [Chesbrough, 2003].

Global experiences over the last two hundred years point to three broad trends. Firstly, almost every large and developed economy in the world has achieved material progress through three sequential but overlapping movements: consolidation and modernization of agriculture, growth of domestic manufacturing followed by its gradual integration into global manufacturing, and growth of the service sector. Secondly, there has been relentless and ever-increasing penetration of technology into every aspect of industry. Thirdly, owing to the emergency of affluent societies, the world market is becoming more and more customer-oriented [Venuvinod, Ma, 2004].

In the last century innovation was treated separately based on its subspecies like product innovation, process innovation, marketing innovation, organizational innovation, technological innovation but nowadays innovation is more frequently handled as a whole concept. Many different innovation subspecies are involved in one process at the same time [Elias, Garayannis, Campell, 2006]. For example, there is an interest is to put a conceptual link between systems and systems theory on the one hand, and their application to knowledge on the other hand. Systems can be understood as being composed of elements tied together by a self-rationale. For innovation, often innovation clusters and innovation networks are regarded as important terms. Ongoing processes of supranational and global integration chronically challenge the popular and powerful concept of innovation clusters and networks. Conceptually unlocking the national innovation systems in favor of a broader multilevel logic implies further accepting the existence of national innovation systems, but at the same time, emphasizing also their global embeddings. Therefore, nowadays several considerations that want to relate to product development different phases, knowledge sharing and product post servicing are integrated more directly and should be understood as a contribution to the general discourse.

As nowadays companies shift from re-engineering and cost-cutting postures to strategic growth initiatives, executives affirm the importance of innovation and new products as critical success factors. In addition, innovation is no longer viewed as belonging to the traditional R&D community. Highly innovative firms now recognize it is a corporate process, demanding management commitment, an inspired vision of the future, and full responsibility of every employee.

Nowadays innovation should be handled as a whole concept of different innovation types, but each of these can be provide novel approaches for making the innovation network model more attractive. Thus in current research, it is investigated, how innovation can be handled in addition for providing remarkable impact for organization business success. For that reason in current study experimental part, innovation capacity is handled from organization employee competences point of view and found how enterprises competences development could lead to business success.

1.2.5 New Product Development and Its Models

The early stage of the NPD process is most usually defined as idea generation, idea screening, concept development and concept testing. Numerous different models have presented the organizational activities undertaken by the company as it embarks on the actual process of NPD. These have attempted to capture the key activities involved in the process from idea to commercialization of the product. Nowadays NPD is mainly viewed from financial perspective, where cash outflows precede cash inflows (see Figure 1.4).

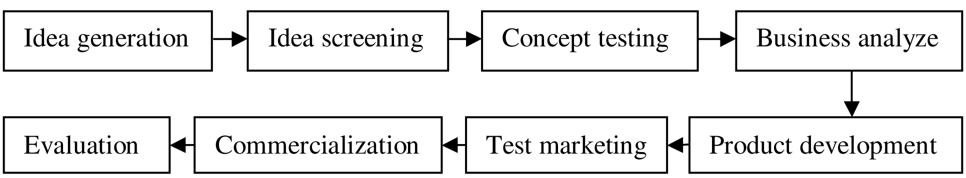


Figure 1.4 Commonly presented linear NPD model

Virtually all those actually involved in the development of NP dismiss such simple linear models as untrue representation of reality. A more recent research suggests that the process needs to be viewed as a simultaneous and concurrent process with cross-functional interaction [Hart, 1993].

NPD is classified into seven distinct categories [Saren, 1984]:
1. departmental-stage models;
2. activity-stage models and concurrent engineering;
3. cross-functional models (teams);
4. decision-stage models;
5. conversion-process models;
6. response models;
7. network models.

Departmental-stage models represent the early form of NPD models. These can be based around the linear model of innovation where each department is responsible for certain tasks. They are usually represented in the following way: R&D provides the interesting technical ideas; the engineering department then takes the ideas and develops possible prototypes; the manufacturing department explores possible ways to produce a viable product capable of mass manufacture; and finally the marketing department plans and conducts the launch. Activity-stage models and concurrent engineering are similar with departmental-stage models, but because they emphasize conducted activities they provide a better representation of reality. They also facilitate iteration of the activities through the use of feedback loops, something that the departmental-stage models do not. More recent activity-stage models have highlighted the simultaneous nature of the activities within the NPD processes. Hence emphasizing need for a cross-functional approach. In activity-stage model the activities occur at the same time but vary in their intensity. Cross-functional models (teams) approach representing people from a variety of functions. The use of cross-functional teams requires a fundamental modification to an organization's structure. In particular, it places emphasis on the use of project management and inter-disciplinary teams. Decision-stage models represent the NPD process as a series of decisions that need to be taken into account in order to progress the project. Like the activity-stage models, many of these models also facilitate iteration through the use of feedback loops. Conversion-process model views NPD as numerous inputs into a „black box" where they are converted into an output. For example, the inputs could be customer requirements, technical ideas and manufacturing capability and the output would be the product. Response models focus on the individual or organization's response to a new project proposal or a new idea. This approach has revealed additional factors that influence the decision to accept or reject NP proposals, especially at the screening stage. Network models suggest that NPD should be viewed as a knowledge-accumulation process that requires inputs from a wide variety of sources.

It is written a lot about NPD models and described how in different models activities in departmental or activity based level can be carried out all together or separately. In order to understand NPD process as the best network concept, product life-cycle should be viewed all together and found, how concurrent engineering could have important impact for making the whole process more effective.

1.3 Concurrent Engineering

Nowadays the worldwide competitive economy forces us to utilize fully the best equipment and techniques available with efficient control of organizational structure to produce high quality and well designed products and services with lower prices and less time. Many figures from all over the world demonstrate that product design should lend itself to all related manufacturing processes so that corporate objectives can be satisfied through an optimized product design [Parsaei, Sullivan, 1998].

- Boothroyd cites (1988) published reports from Ford Motor Company, which estimate even through product design account for only 5% of total product cost, 70% of the cost is influenced by design.
- Hutwaite (1987) shows the same percentages of product cost and influence and calls the influence of the product design „Ripple effect“ that can virtually impact every area of an organization. The product design function can therefore be imagined as a rock thrown into the center of lake, which signifies a corporate organization.
- In 1988 it was believed that 40% of all quality problems are traceable to poor design.
- Suh (1990) believed that as much as 70-80% of manufacturing productivity could be determined at the design stage.
- Gatenby and Foo (1990) estimated that an even higher percentage (from 80 to 90%) of the total life-cycle cost of a product is determined during the design phase.
- An observable statement of a manufacturing executive quoted in a prestigious paper (1990): „designers make million-dollar decisions every minute without ever knowing it“.

In this context, concurrent engineering (CE) has been recently recognized as a visible approach in which the simultaneous design of a product and all its related processes in manufacturing system are taken into account, ensuring required matching of the product’s structural with functional requirements and the associated manufacturing implications. This means that all pertinent information flows should be multi-directional among the design function and all related processes in an organization.

An overview of literature reveals that only little or even nothing was written about „concurrent engineering“ or „simultaneous engineering“ or „simultaneous product development“ before 1980. Therefore it appears that concurrent engineering is a relatively recent concept in management and engineering. The following provides an overview about the concurrent engineering concept together with its main principles, where this business and manufacturing strategy has been implemented. Through the chapter the principles of CE are explained and additional detected benefits from research pointed out.

Many different people and organizations have described Concurrent Engineering (CE). There are many other names that have been applied to the same principles such as simultaneous engineering, integrated product and process design, concurrent design, etc. These terms are still in use, because CE is defined differently by different people. But the Institute developed the original definition that is frequently referred to in 1986 for Defense Analyses: "Concurrent Engineering is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule, and user requirements" [CERC Technical Report, 1992].

Many other definitions have been published since then. Most of them focus on integration and managing the design process to result in a shortened time-to-market. The following list indicates how differently authors view concurrent engineering:

- A systematic approach to integrated product development that emphasizes the response to customer expectations. It embodies team values of cooperation, trust and sharing in such a manner that decision making proceeds with large intervals of parallel working by all life-cycle perspectives early in the process, synchronized by comparatively brief exchanges to produce consensus.
- CE is a management and engineering philosophy for improving quality and reducing cost and lead time from product conception to product development for new products and product modifications [Creese, Moore, 1990].

On the other hand, it has been mentioned that concurrent engineering is a business strategy which replaces the traditional product development process with one in which tasks are performed in parallel and there is an early consideration for every aspect of a product's development process. This strategy focuses on the optimization and distribution of a company's resources in the design and development process to ensure effective and efficient product development process. CE is a systematic approach to the integrated, simultaneous design of both products and their related processes, including production [Unasekaran, 1998].

1.3.1 Need for Concurrent Engineering

Why does business nowadays need concurrent engineering? It is really important for companies to be able to react to the changing market needs rapidly, effectively and responsively. They must be able to reduce their time to market and adapt to the changing environments. Therefore, decisions must be made quickly and effectively. There is no time for overdue and it is not acceptable to repeat the tasks or prolong the time in bringing a new product or service to the market. Therefore, more and more companies have realized that concurrent engineering enables them to bring rapid solutions to product development processes.

Concurrent engineering is indisputably the wave of the future for new product development for all companies regardless of their size, sophistication, or product portfolio. In order to be competitive, companies must be able to complete diverse tasks simultaneously. Activities should be clustered, integrated and managed concurrently rather than sequentially in order to save time [Shtub, Bard, Globerson, 1994]. An old traditional sequential path has not entailed the dialogue between design and the downstream processes (see Figure 1.5 and 1.6) [Smith, Reinersten, 1991], [Skalak, 2002].

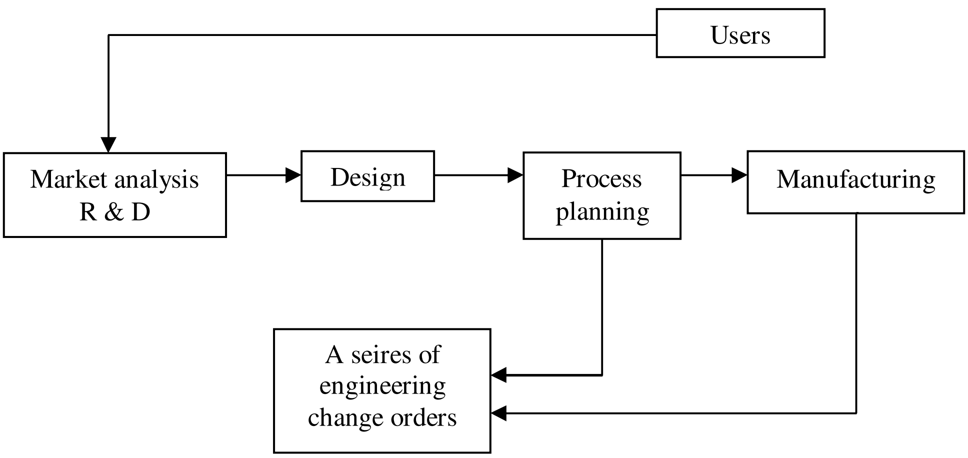


Figure 1.5 Sequential product development cycle

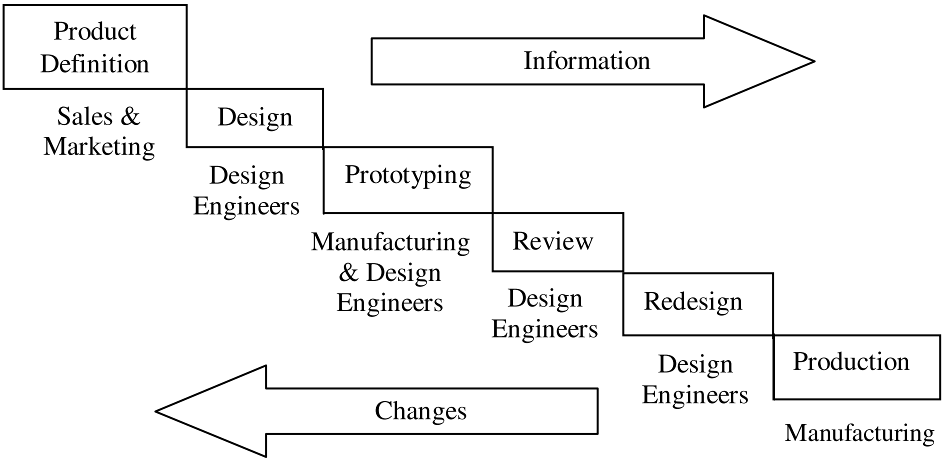


Figure 1.6 Flow diagram of sequential concurrent engineering process

But the new CE process will benefit the company, although it requires a large amount of refinement in its implementation, because it must be reviewed and adjusted for continuous improvements of engineering and business operations.

In order to sum up the Concurrent Engineering approach, it can be said that it is a business strategy, which replaces the traditional product development process with one in which tasks are performed in parallel and there is an early consideration for every aspect of a product's development process. This strategy focuses on the optimization and distribution of a company's resources in the design and development process to ensure an effective and efficient product development process. It includes major changes within the organizations and companies that use it due to the people and process integration requirements. Collaboration is needed between individuals, groups, departments, and separate organizations within or outside the company. Dedication to long term implementation, appraisal and continuous revision are strongly needed in a concurrent engineering process.

1.3.2 Strategic Plan of Concurrent Engineering

Concurrent engineering is recognized as a strategic weapon that businesses must use for effective and efficient product development. This product development process is not a trivial task, but as already mentioned before, it is a complex strategic plan that demands full organization commitment together with strong leadership and teamwork.

How to apply concurrent engineering? This is not a trivial process to apply. If a company is going to commit the concurrent engineering process it must first of all devise a plan. This plan must create organizational change throughout the entire company or firm. In addition, there must be a strong commitment from the company's leadership in order to mandate the required organizational changes from top to down. Concurrent engineering does not work without leadership, because otherwise there will be no clear direction or goal. Concurrent engineering is a long-term strategy and it can be considered only by organizations, which are willing to make quick product providing for the market. As this business process can involve major organizational and cultural changes, excellent leadership skills are always needed. The main problems with product development performance that concurrent engineering aims to overcome are those of the traditional serial product development process in which people from different departments work one after the other on successive phases of development. Therefore, a clear vision is always needed, so that every employee understands the expectations and estimated time for the work performed.

On the other hand, of course concurrent engineering with leadership, management support, and proper planning will bring success in contemporary challenging market. To ensure a continuous improvement process, it is important to understand its entity. Concurrent engineering is not just a one-size fit all solution to a company's development processes. There are many different aspects, which may or may not fit in an organization's development process. Concurrent engineering is only a set of process objectives and goals that have a variety of implementation strategies. Therefore, it is an evolving process that requires continuous improvement and refinement. This continuous improvement cycle consists of planning, implementing, reviewing and revising. The process must be updated and revised on a regular basis in order to optimize its effectiveness and benefits in the concurrent engineering development process. Thus, also in current study CE is implemented in best-practice approaches. In experimental part of research, it is investigated, how CE can be adjusted to NPD processes in rapid prototyping case-studies, where simultaneous work between different area engineers are needed in order to reach to the final result more quicker than continuing each development tasks in sequential way.

In addition, not only continuity is important, but communication and collaboration, as well. The implementation of concurrent engineering begins actually by creating a corporate environment that facilitates communication and collaboration not just between individuals, but also between separate organizations and departments within and without the company. Therefore, a company that wants to implement a concurrent engineering process should be prepared for the following: structural changes, re-education of the existing work force and/or restructuring of the development process. This attitude will be investigated in more detail in experimental part case-studies and it will be resulted that project based changes in general CE process are needed for achieving better results in product development project.

1.3.3 Basic Principles of Concurrent Engineering

The goal of CE is to improve the interactive work of different disciplines affecting a product [Adebayo, 1994]. According to Cline [Cline, 2000], CE has seven main goals, which are based on its principles (see Table 1.3)

Table 1.3 A model to illustrate goals of Concurrent Engineering

Project identification	Ensure a single direction for corporate development in order to avoid shifting priorities, false project starts and pre-emptied project efforts.
Project scope	Estimate the project's effort, time and cost so that executives can make an informed decision about project's worth.
Requirement and analysis	Build and validate a model of the business problem domain in order to ensure the correct problems and to define customer needs.
System design	Provide technical solution that meets the customer needs and enhances corporate business value.
Development planning	Define a work plan for implementing ideal technical solution.
Construction	Install or construct the solution, using a mini-release, risk-driven and priority-driven approach, to run concurrently with testing and low-level design.
Installation and assessment	Ensure a solid and methodical way of moving the product into the customer's environment as smoothly as possible.

A conceptual methodology has been developed from the seven principles above. From the conceptual methodology (see Figure 1.7), it can be seen that the process of undertaking CE is a systematic approach to an integrated, concurrent design of products, process and installation of plant and processing of products, considering the related downstream aspects and elimination of non-value adding activities.

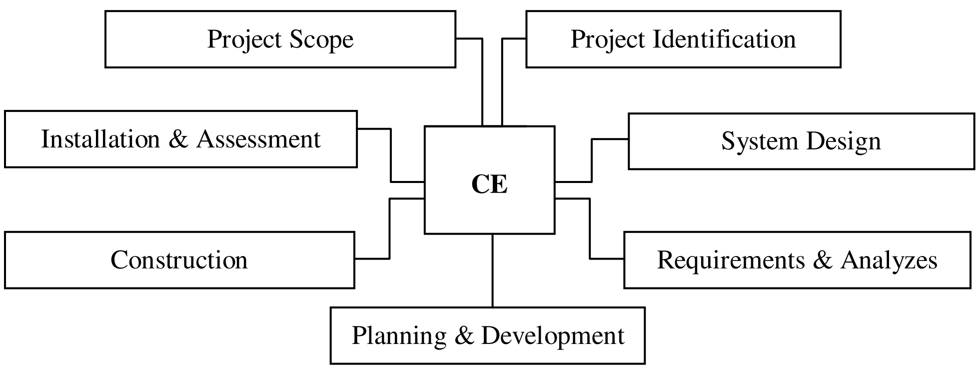


Figure 1.7 Conceptual methodology for Concurrent Engineering

The CE approach can be achieved through a multidisciplinary team approach which intends to motivate process designers, plant designers and installers and other participants throughout various design processes, to consider all elements of the product life cycle from the inception through to disposal of product, taking into consideration quality, cost, time-effectiveness, rapid adaptation of system to evolving business environments and end user requirements [Gunasekaran, Adebayo, 2000].

Basic principles of the CE by the President of DRM Associates, a management consulting and training firm specializing in new product development through the implementation of best practices; time-to-market and integrated product development concepts; product planning, tools and techniques, are the followings:

1. Understand customer needs and manage requirements.
2. Get strong commitment from senior management.
3. Plan and manage PD.
4. Use PD teams.
5. Integrate process design.
6. Manage costs from the start.
7. Involve suppliers and subcontractors.
8. Develop robust.
9. Integrate CAE, CAD, CAM & CASE tools.
10. Simulate product performance and manufacturing processes.
11. Create an efficient development approach.
12. Improve the design process.
13. Manage the project effectively.
14. Complete all tasks in parallel.

Therefore it can be said, that Concurrent Engineering is not a quick fix for a company's problems and it is not an only way to improve engineering performance. It is a business strategy with many different principles that have to be taken into account in order to improve the company’s product development performance.

1.3.4 When to Use Concurrent Engineering

In traditional serial product development, the product is first completely defined by the design-engineering department, after which the manufacturing process is defined by the manufacturing engineering department, etc. Usually the process is quite slow and costly. The approach can be of low quality and lead to a lot of engineering changes, production problems, product introduction delays and finally to a developed product that is less competitive than it was planned.

Therefore the majority of a product's costs are defined very early in the design and development process. In that case companies apply concurrent engineering at the onset of the project. This makes concurrent engineering a powerful development tool that can be implemented early in the conceptual design phase where the majority of the products costs are defined. Here are several applications in which concurrent engineering may be used. Some primary applications include product research, design, development, re-engineering, manufacturing and redesigning of existing and new products. In these applications, concurrent engineering is applied throughout the design and development process to enable the firm to reap the full benefits of this process. Only in case the whole team of product developers of different functions co-operates on all levels from the start of the project, is possible to arrange the process efficiently. A cross-functional team may contain representatives of different functions such as system engineering, mechanical engineering, electrical engineering, systems reducibility, fabrication reducibility, quality, reliability and maintainability, testability, manufacturing, drafting and layout, program management and etc. For example, sometimes only design engineers and manufacturing engineers are involved in Concurrent Engineering. In other cases, cross-functional teams include representatives from purchasing, marketing, production and quality assurance and from other functional groups. In addition, even customers and suppliers can be included in the team.

1.3.5 Why to Use Concurrent Engineering

There are many reasons why companies use CE. They do so mainly because of the possibility to achieve competitive advantage. Secondly, it can help to increase performance and finally, it helps to reduce design and development times. Therefore, the main reasons for using concurrent engineering are related to the possibility of cutting benefits and achieving competitive advantage. This business strategy suits companies of all sizes, large or small. While there are several obstacles to initially implement in concurrent engineering, these obstacles are minimal when compared to the long-term benefits that concurrent engineering offers. Secondly, smart companies can easily understand and recognize that concurrent engineering is as a key factor for improving the quality, development cycle, production cost and delivery time of their products. It is very effective, because it enables the early discovery of design problems and thereby companies can be addressed up front rather than later in the development process. Concurrent engineering helps to eliminate multiple design revisions and re-engineering efforts and enables to create an environment for designing properly from the beginning.

Regarding reduced design and development times it can be said that companies, that use concurrent engineering are able to transfer technology to their markets and customers more effectively, rapidly and predictably. Those companies will be able to respond to customer’s needs and wishes. Therefore, they are able to produce quality products that meet or exceed the consumer's expectations. In addition, if necessary they are able to improve and bring quicker upgrades to their existing products through concurrent engineering practices. Therefore, companies that use concurrent engineering will be able to produce better quality products, developed in shorter time and at lower cost, thus meeting the customer's needs [Auyang, 2006]. Therefore, it can be said that concurrent engineering produces a unified profitable corporation and a satisfied consumer [Rehg, Kraebber, 2004].

Some main potential advantages of using concurrent engineering are described in literature and are collected from different resources:

- Products reach the market quicker that result in increased market share.
- Lower manufacturing and production costs.
- Improved quality of final products.
- Increased positioning in a highly competitive world market.
- Increased accuracy in predicting and meeting project plans, schedules, timelines and budgets.
- Increased efficiency and performance.
- Higher reliability in the product development process.
- Reduced defect rates.
- Increased effectiveness in transferring technology.
- Increased customer satisfaction.
- Ability to execute high level and complex projects while minimizing the difficulties.
- Shorter design and development process with accelerated project execution.
- Higher return on investments.
- Reduction or elimination of the number of design changes and re-engineering efforts at later phases in the development process.
- Reduced labor and resource requirements.
- Ability to recognize necessary design changes early in the development process.
- Increased innovation by having all players participate in the concept development phase.
- Ability to design accurately from the beginning.
- Overlapping capabilities and the ability to work in parallel.
- Increased cohesiveness within the company.
- Increased bureaucracy within the company.
- Improved communication between individuals and departments within the company.
- Lower implementation risks.
- Faster reaction time in responding to the rapidly changing market.
- Lower product and process design and development costs.
- Improved inventory control, scheduling and customer relations.

In current study, CE will be also implemented in case of rapid prototyping case studies. Mainly, because CE helps to make product development process much effective. It was already mentioned, that CE approach enables to work parallel in product life-cycle and prevent necessary changes in final products. In addition, it is necessary for improving quality and reducing cost and development time. The general CE model is well-known, but its implementation can be different for separate product development projects. In different product development phases different important key-factors should be considered for achieving best results. Therefore, in current study CE approach is also implemented and viewed mainly in the first phase of product development - in prototyping phase. It will be investigated, how simultaneous works between different area engineers could lead to project success as it is described to be possible also in case of simultaneous work between different departments during the whole product life-cycle process. CE conception is describing how to use all its principles concurrently rather than sequentially. In case of conceptual model of CE, different activities are carried out simultaneously in order to achieve above mentioned objectives of CE. But it is not written, how each part of CE conceptual model can be improved via implementing new methodologies for example in concept design or prototyping phase. For that reason CE is implemented in current study experimental part case-studies and investigated, how modularization approach could help to make the CE process even more effective.

1.4 Data Mining

Data Mining (DM) is a general term, which encompasses a number of techniques to pick out useful information from large data files and enables to sort it. It is a new powerful technology for analyzing data from different perspectives and summarizing it into useful information. It has been also said that data mining is the analyses of (often large) observational data sets to find unsuspected relationships and to summarize the data in novel ways that are both understandable and useful to the data owner [Tsai, Chen, Chan, 2008]. Nowadays it is also very often known as Knowledge Discovery in Databases (KDD) [Larose, 2006] or simply Knowledge Discovery (KD) [Wikipedia, 05/04/2011]. It enables to identify trends within data that go beyond simple analysis and through the use of sophisticated algorithms; users have the ability to identify key attributes of business processes and target opportunities. Data mining is predicted to be "one of the most revolutionary developments of the next decade", according to the online technology magazine ZDNET News (February 8. 2001). In fact, the MIT Technology Review has chosen the data mining as one of ten emerging technologies that will change the world.

Therefore, this technology is a new developing cross-disciplinary subject. With the development of computer technology, the application of data mining technology to analyze large amounts of realistic data has become the most advanced orientation in the field of data mining in the world. Data mining technology is often used together with many other theories and technologies such as data bases, artificial intelligence, machine learning, statistics, etc, and it is applied in the industries of finance, insurance, telecommunications and retail, which have accumulated a great quantity of data [Siqing, Yin, Yan, 2003]. Some of the first business areas with an early adoption of data mining into their processes are banking, insurance, retail and telecom. More recently it has been adopted also in pharmaceutics, health and government. The most well known business applications of DM technology are in marketing, customer relationship management and fraud detection. Other applications include monitoring, information extraction and risk analysis.

Data Mining has been used widely by companies with a strong consumer focus and marketing organizations, where it enables to determine relationships among "internal" factors such as price, product positioning, and "external" factors such as economic indicators, competition, and customer demographics [Hand, Mannila, Smyth, 2001]. There are many different possibilities for using data mining but the most frequent examples encompass mainly these applications:

- Rate customers by their propensity to respond to an offer.
- Identify cross-sell opportunities.
- Detect fraud and abuse in insurance and finance.
- Estimate probability of an illness re-occurrence or hospital re-admission.
- Isolate root causes of an outcome in clinical studies.
- Determine optimal sets of parameters for a production line operation.
- Predict peak load of a network.

Data mining is a field where research and applications are strongly related. On the one hand, applications drive research and research results often find applicability in real world applications [Soares, Peng, Meng, Washio, Zhou, 2008]. In spite of this closeness between research and application and the amount of available information about DM, it is still quite hard to find information about some of the most important issues involved in real world application of DM technology. These issues include data preparation (e.g., cleaning and transformation), adaptation of existing methods to the specificities of an application, combination of different types of methods (e.g., clustering, classification) and testing and integration of the data mining solution with the Information System (IS) of the company. Not only do these issues account for a large amount of time of a data mining project but they often determine its success or failure [Kohavi, Provost, 2001).

The general Data Mining Process (DMP) (see Figure 1.8) includes six phases that address the main issues in data mining. All these phases fit together in cyclical process and cover the full data mining process [Lentzsch, 2007].

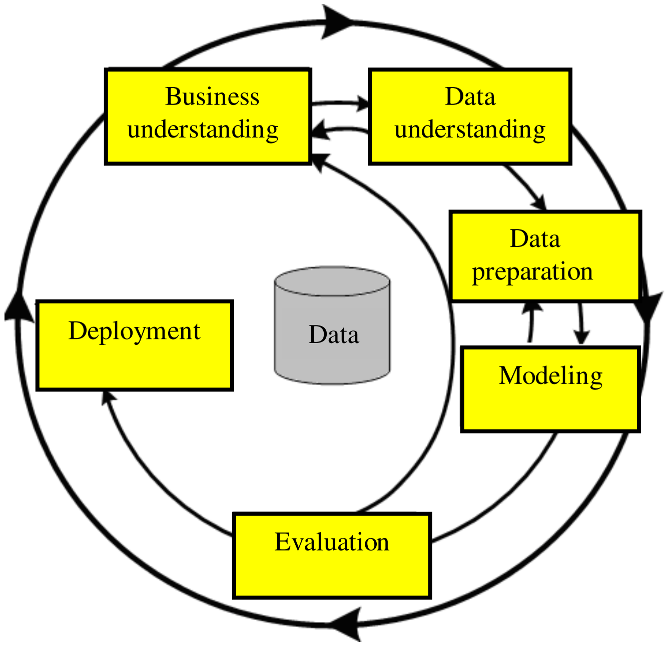


Figure 1.8 Data Mining Process, according to the CRISP-DM methodology

This process is also known as the leading data mining methodology – CRISP-DM (Cross Industry Standard Processing for Data mining) [Chapman, Clinton, Kerber, Khabaza, Reinartz, Shearer, Wirth, 2000]. CRISP-DM was launched as a European Union project under the ESPRIT funding initiative. Four companies were the initiators: ISL, NCR, Daimler-Benz and OHRA and the first version of the methodology was released as CRISP-DM 1.0 in 1999. It has been developed as an industry- and tool-neutral Data Mining process model, which makes large data mining projects faster, cheaper and more reliable and manageable [Roiger, Geatz, 2003]. Methodologies, such as CRISP-DM, typically organize data mining projects into the following six steps that were presented also on Figure 1.8: business understanding, data understanding, data preparation, modeling, evaluation and deployment. Next, all the above mentioned six steps are discussed in the following in greater detail:

Business and Data Understanding

In the business understanding step the goal is to clarify the business objectives for the project, where data mining will be implemented. The second step is data understanding that consists of collecting and becoming familiar with the data available for the project. Those steps are highly affected by application-specific issues. Domain knowledge is required in order to understand the whole context of a data mining project: determine suitable objectives, decide which data should be used and understand their meaning and relevance through the project [Ni, Cao, Zhang, 2008].

Data Preparation

Data preparation consists of a diverse set of operations to clean and transform the data in order to make it ready for modeling. Many of those operations are independent of the application operations like missing value imputation or discretion of numerical variables. On the other hand, much of the data preparation step consists of application-specific operations, such as feature engineering. For example, combining some of the original attributes into a more informative one.

Modeling

In the modeling step, the data resulting from the application of the previous steps is analyzed to extract the required knowledge. In some applications, domain-dependent knowledge is integrated in the data mining process in all steps except this one, in which off-the-shelf methods/tools are applied. A different modeling approach consists of developing/adapting specific methods for a problem. Some applications involve novel task that require the development of new methods. An example is the work of Datta [Datta, Hu, Ray, 2008], who addresses the problem of predicting resource demand in project planning with a new sequence mining method based on hidden semi-Markov models [Datta, Hu, Ray, 2008]. Other applications are not as novel but have specific characteristics that require adaptation of existing methods. For instance, the approach to the problem of generating trading rules uses an adapted evolutionary computation algorithm [Ni, Cao, Zhang, 2008]. In some applications, the results obtained with a single method are not satisfactory and thus, better solutions can be obtained with a combination of two or more different methods. A data analyst must also be prepared to use methods for different tasks and originating from different fields, as they may be necessary in different applications, sometimes in combination as described above. The applications cover tasks such as clustering, classification, regression, information retrieval and extraction, association mining and sequence mining. Many research fields are also covered, including neural networks, machine learning, data mining, statistics (e.g., logistic and linear regression) and evolutionary computation. The wider the range of tools that is mastered by data analyst, the better results analyst may obtain [Toro-Negro, Garcia-Teodoro, Diaaz-Verdejo, Macia-Fernandez, 2008].

Evaluation

The goal of evaluation step is to assess the adequacy of the knowledge in terms of the project objectives. The influence of the application on this step is also quite clear. The criteria selected to evaluate the knowledge obtained in the modeling phase must be aligned with the business goals. For instance, the results obtained on the online advertising application can be evaluated in terms of click through and also of revenue [Giuffrida, Cantone, Tribulato, 2008]. Therefore finding adequate evaluation measures is a complex problem. A methodology to support the development of a complete set of evaluation measures that assess quality not only in technical, but also in business terms [Luo, Cao, Luo, Zhang, Wang, 2008].

Deployment

Deployment is the step in which the knowledge validated in the previous step is integrated in the decision making process of the organization. Thus, it depends heavily on the application context. Despite being critical for the success of a data mining project, this step is often not given sufficient importance, in contrast to other steps such as business understanding and data preparation. This attitude is illustrated quite well in the CRISP-DM guide, as well. In many cases it is the customer, not the data analyst, who carries out the deployment steps. However, even if the analyst will not carry out the deployment effort it is important for the customer to understand up front what actions need to be carried out in order to actually make use of the created models [Chapman, Linton, Kerber, Khabaza, Reinartz, Shearer, Wirth, 2000]. This graceful handing over of responsibilities of the deployment step by the data analyst can be the cause for the failure of a DM project which, up to this step, has obtained promising results. In some cases, the model obtained is the core of the business process. Thus, deployment requires the development of the software system (e.g., program or website) that will serve as a wrapper to the model. Sometimes integration typically implies communication with one or more databases and with other modules. It may also be necessary to implement communication with external entities, such as users or hardware. Finally, because it cannot be guaranteed that a model developed with existing data will function correctly forever, monitoring and maintenance mechanisms must be implemented. Monitoring results should be fed back to the data analyst, who decides what should be done (e.g., iteration in the DM process). In some cases it is possible to implement an automatic maintenance mechanism to update the model, e.g. by relearning the model using new data. For instance, the model for personalization of ads can be updated daily with new data that is collected from the activity on the ad-server [Giuffrida, Cantone, Tribulato, 2008]. Additionally, development of typical data mining projects uses real data, but it is usually independent of the decision process, which it aims to improve. Quite often, the conditions are not exactly the same in the development and the deployment contexts. Therefore, it may be necessary in some cases to carry out a gradual integration with suitable live testing. The development of mechanisms to support this kind of integration and testing implies changes to the IS of the organization, with associated costs.

As DM is not well-known and rarely implemented methodology in industrial engineering sector, it was necessary to investigate DM method also in current study. Therefore, in experimental part of current study, DM implementation preconditions need to be researched in more detail for enabling to analyze enormous amount of data that was gathered about Estonian apparatus, metal working and machinery enterprises competences and technological capabilities. Thus, it was necessary to investigate DM methodology possibilities also in industrial engineering and to propose, how its implementation could help to achieve higher innovation capacity in Estonian industrial enterprises.

1.5 Rapid Prototyping

Previous means of producing a prototype required man-hours, many tools and skilled labor. For example, after a new street light luminary was digitally designed, drawings were sent to skilled craftsmen where the design on paper was painstakingly followed and a three-dimensional prototype produced in wood by utilizing an entire shop full of expensive wood working machinery and tools. This was not a speedy process and costs of the skilled labor were not cheap. Hence, there was the need for developing a faster and cheaper process to produce prototypes. As an answer to this need, rapid prototyping (RP) was born in the late 1980s and was successfully used to produce models and prototype parts [Grenda, 2006]. Since the late 1980s the rapid prototyping has evolved from a tool for making factory modules and dies to a low-volume technique for making finished parts, even consumer product prototypes [Gross, 2003]. The rapid prototyping technologies now evolve toward rapid tooling. The reasons for this extension are found in the need to further reduce the time-to-market by shortening not only the development phase, but also the industrialization phase of the manufacturing process [Karapatis, Griethuysenj, Glardn, 1998]. Nowadays many different RP methods are available.

Rapid prototyping is a faster, more cost-effective method for building prototypes from three-dimensional computer-aided design (CAD) drawings. It provides a fundamental overview of the general manufacturing process and presents the principles and applications of designing and fabricating parts in a format that makes learning easy [Noorani, 2006].

On the other hand, rapid prototyping is the automatic construction of physical objects using additive manufacturing technology. The first techniques for rapid prototyping which became available in the late 1980s were used to produce models and prototype parts. Today, they are used for a much wider range of applications and are even used to manufacture production-quality parts in relatively small numbers. Some sculptors use the technology to produce complex shapes for fine arts exhibitions [Wohlers Report 2009].

The use of additive manufacturing technology for RP takes virtual designs from computer aided design (CAD) or animation modeling software and transforms those into thin, virtual, horizontal cross-sections and then creates successive layers until the model is completed. It is also called as a WYSIWYG process where the virtual model and the physical model are almost identical [Mayer, 1998].

With additive manufacturing, the machine reads in data from a CAD drawing and lays down successive layers of liquid, powder, or sheet material, and thus, this way builds up the model from a series of cross sections. These layers, which correspond to the virtual cross section from the CAD model, are joined together or fused automatically to create the final shape. The primary advantage to additive fabrication is its ability to create almost any shape or geometric feature.

The standard data interface between CAD software and the machines is the STL file format [Kalpakjian, Serope, Schmid, 2006]. An STL file approximates the shape of a part or assembly using triangular facets. Smaller facets produce a higher quality surface. The word "rapid" is relative: construction of a model with contemporary methods can take from several hours to several days, depending on the method used and the size and complexity of the model. Additive systems for rapid prototyping can typically produce models in a few hours, although it can vary widely depending on the type of machine used and the size and number of models produced simultaneously.

Rapid prototyping is now entering the field of rapid manufacturing and it is believed by many experts that this is a "next level" technology [Hopkinson, Hague, Dickens, 2005].

The main reasons for rapid prototyping are the followings:

- to increase effective communication;
- to decrease development time;
- to decrease costly mistakes;
- to minimize sustaining engineering changes;
- to extend product lifetime by adding necessary features and eliminating redundant features early in the design.

Rapid prototyping decreases development time by allowing amendments to a product to be made early in the process. By giving engineering, manufacturing, marketing, and purchasing a look at the product early in the design process, mistakes can be corrected and changes can be made while they are still inexpensive. Therefore, trends in manufacturing industries continue to emphasize the following:

- increasing number of variants of products;
- increasing product complexity;
- decreasing product lifetime before obsolescence;
- decreasing delivery time.

Rapid prototyping improves product development by enabling better communication in a concurrent engineering environment [Venuvinod, Ma, 2004].

Choosing prototyping for a product development is a very complicated matter and it depends on many factors, such as cost trade-off, cycle time, accuracy of prototyped part, material property, part size, part strength and availability. Most importantly, the selection should be based on the prototyping objectives. A prototype can be a physical prototype in which artifacts are created to approximate the product. For example, models that look and feel like the product.

Prototype classification is shown on Figure 1.9 [Liou, 2007].

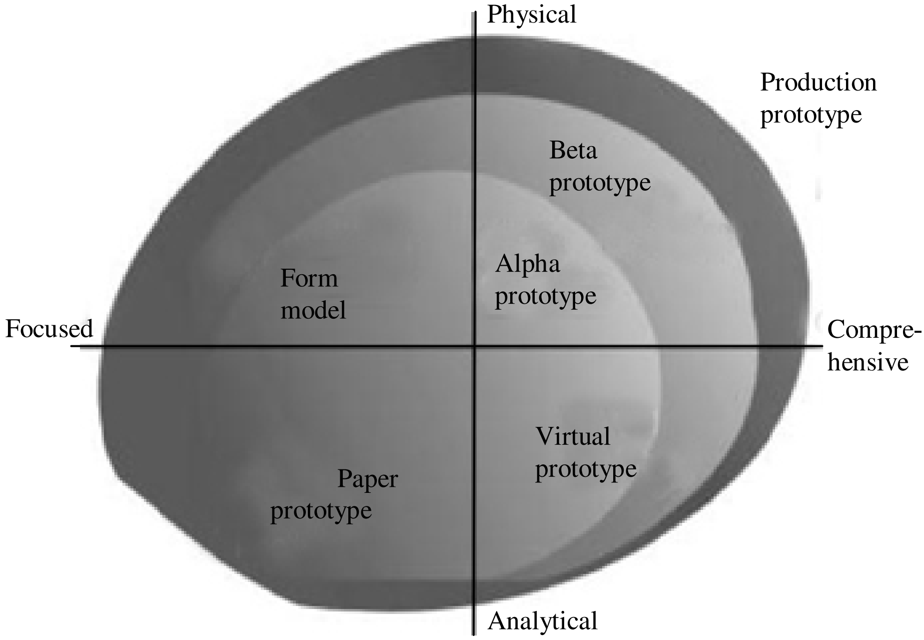


Figure 1.9 Prototype classifications

A physical prototype is commonly used for proof of concept to test the idea and used as an experimental hardware to validate functionality of a product. However, a prototype can also be an analytical prototype in which mathematical, analytical, simulation or a computer model is used to analyze the product. A prototype can be comprehensive prototype – full-scale, fully operational version of the product. For example, a beta prototype is given to customers in order to identify any remaining design flaws before committing to production. A prototype can be a focused prototype to implement on or a few of the attributes of the product (work-like or look-like product). A paper prototype, which could be a sketch of a concept of the kinematics of a product, is an analytical and focused prototype. Form model to show the „look“ of a prototype is a physical but focused prototype. An analytical but comprehensive prototype is likely to be a full model-based virtual prototype, which could include the full geometry, kinematics, dynamics, FEA model, and many other aspects of the product. Simulation technologies are getting better and more accurate, and it is possible that an analytical model could be a comprehensive model. A physical and comprehensive model could be an alpha, beta, or production prototype. An alpha prototype is the first system construction of the subsystem that is individually proven to work while a beta prototype is the first full-scale functional prototype of a product constructed from the actual materials as the final product. A preproduction prototype is the final class of physical model used to perform a final part production and assembly assessment using the actual production tooling.

Nowadays there are a large number of competing technologies available in the market (see Table 1.4). As all are additive technologies, their main differences are found in the way layers are built to create parts. Some are melting or softening materials to produce the layers (SLS, FDM) where others are laying liquid materials thermo sets that are cured with different technologies. In the case of lamination systems, thin layers are cut to shape and joined together [Pham, Dimov, 2001].

Table 1.4 RP technologies

Prototyping technologies	**Base materials**
Selective Laser Sintering (SLS) (also known as Plastic Laser Sintering Technology (PLST)	Metals powders, thermoplastics
Fused Deposition Modeling (FDM)	Thermoplastics, eutectic metals
Stereo Lithography (SLA)	Photopolymer
Laminated Object Manufacturing (LOM)	Paper
Electron Beam Melting (EBM)	Titanium alloys
Inkjet Printing Technology (IPT)	Various materials

As RP is fastest and more cost-effective method for building prototypes, it is widely used activity in NPD process for giving clear overview of the final product. In addition, in RP, analytical prototype enables to get an overview of the developed functionality. Thus this methodology not only gives clear vision of the product but enables also to carry out different test-processes for finding and analyzing product failure risks. For that reason it is necessary to be familiar with different RP technologies and know these pros and cons. It is written a lot that in recent years three-dimensional printing (3DP) has emerged as a very competitive process in terms of cost and speed, an sales of related equipment have increased significantly compared to the other RP machines [Wohlers, 2005]. A lot of studies about successful rapid prototyping case-studies can be found and it is remarkable, how for example the questions of printing accuracy in these most successful case studies have been carefully avoided [Dimitrov, 2006]. As in earlier practice in Estonia it is noticed that using 3DP technology, some problems with printed part fitting can be occurred. Therefore, it was necessary to analyze based on case studies, how his problem can be prevented and find out the methodology for minimizing the risk, where physical prototypes dimensions differentiate from virtual prototype dimensions. In addition, as it was said that 3D-printing shortens the product development time and accelerates the time it takes the product to reach the market, it was necessary to understand, which RP technology enables to do it most effectively. For getting wider overview about different RP technologies, more detail analyze about different RP technologies was needed based on different comparison criteria. It was necessary to find these technologies pros and cons, because in case of different RP projects, the objectives could be different and making right selection of RP technology impacts important role for the project success. For that reason RP currently occurred “bottlenecks” are analyzed in current study experimental part and improvement successions need to be investigated for more effective product development process.

2 THE OBJECTIVES AND PLANNED ACTIVITIES

2.1 Objectives

The objective of the doctoral thesis is to increase innovation capacity in Estonian SME enterprises via proposing additional key-drivers for innovation and more efficient product development.

2.2 Main Starting-Points for Problem Solving

3 main starting-points have been handled in order to find additional key-drivers for making product development process more effective. Therefore research issued from the following main fundamental problems:

1. Rapid Prototyping “bottlenecks” should be analyzed and improvement successions for better product development verified.
2. The influence of innovation to productivity should be analyzed from the enterprise employee’s competence point of view. Advisory system for making recommendations regarding product development team selection should be proposed.
3. Data Management methods implementation should be analyzed in more detail for proposing more effective analyze method for machinery enterprises data analyze and for increasing customer service quality in e-business.

2.3 Planned Activities

For achieving the described objective, we had to study some tasks. The planned activities were as follows:

1:

- To analyze 3 well-known rapid prototyping methods based on additional comparison criteria in order to compare these advantages and disadvantages;
- To analyze concurrent engineering and modularization impact for new product development process based on real rapid prototyping case studies;
- To analyze printed part dimensions in order to propose the solution for printed part accuracy problems prevention.
- To investigate printable part positioning influence to the strength of prototype;

2:

- To develop engineering industry enterprises competence cards and collect data about employee's existing and needed level competences in Estonian machinery building, metalworking and apparatus industry companies;
- To analyze data and investigate additional training needs for improving enterprise employee's existing level of competences;
- To develop solution for innovation capacity estimation in enterprises;

3:

- To analyze Data Mining preconditions for this methodology implementation in engineering industry;
- To investigate new approaches in data management for improving customer service quality and increase customer satisfaction regarding e-services.

To integrate all previously listed task results so that these could be handled as important key- drivers for innovation and new product development process.

3 EXPERIMENTS

The current chapter covers the first starting point that was introduced in the previous chapter and is the one of three main key-points for the current study. Therefore, the key-drivers will be viewed from the new product development and rapid prototyping point of view.

Enterprises who are contacting with product development processes in their every day work, should know, how via RP process improvement can improve development projects success. In current practice different “bottlenecks” have been occurred with suitable RP technology selection, which impact affect not only for prototyping speed but also for the quality of prototype. In addition, in order the development process could be more effective, it is recommended to implement CE. But the well-known methodology is not meant only for the whole development process, but can be implemented also in the beginning of product development phase - in concept generation, rapid prototyping and product testing phases. This early involvement of CE methodology enables to handle concept generation, prototyping and tests with prototype simultaneously already in the early phase of product development. For that reason, based on real practice different case studies will be studied in experimental part of current study and planned activities (see first part of planned activities in chapter 2.3) regarding RP “bottlenecks” preventions proposed.

The challenge how to stay competitive in the market(s) is still a question mark for many enterprises. The products have various functional requirements, whereas product cost, quality and time-to-market are the main key-factors in product development. The product development cycle time for almost all products has steadily decreased over the years and the quality and cost relation has been getting better [Liou, 2007]. It is because enterprises that use 3D prototypes have found out that the opportunity for 3D printing enables them to produce three-dimensional “form-and-fit” concept models, which are primary used for visualizing and communicating early product design. Such approach enables quick “print” and fast prototype presenting to marketing people and toolmakers. It is already known, that the rapid prototyping method – 3D printing, shortens the product development time and accelerates the time it takes the product to reach the market. But there are still some bottlenecks, that can be eliminated and thus the whole rapid prototyping process improved.

Firstly, the word "rapid" is actually relative. It means that construction of a model with contemporary methods can take from several hours to several days, depending on the method used and the size and complexity of the model. On the other hand, additive systems for rapid prototyping can typically produce models in a few hours, although it can vary widely depending on the type of machine used and the size and number of models produced simultaneously. Thus, choosing right prototyping method requires right decisions. Especially in order to win the competitors, product development time has to be as quick as possible. For that reason most widely known RP technologies were compared in this study and results presented in the current chapter. Understanding pros and cons of each technology can lead to one important key-point that should be taken into account for achieving more effective results in the whole product development process.

The second issue that will be investigated in order to improve RP process is to involve concurrent engineering and modularization ideology into product development. Rapid prototyping is recognized as a significant technology for future product development and today more and more manufacturers experience immense pressure to provide a greater variety of complex products in shorter product development cycle. The evolution of the market needs the time-to-market reduction, mainly because the product life cycle is shorter and also because it is very important to produce more rapidly from an initial conception or „idea" to a mass production product [Ferreira, 2006]. But there still exist some deficiencies that can be improved by involving concurrent engineering and modularization into product development process already in the prototyping phase. Therefore, the real case study has been implemented by taking into account CE and modularization principles altogether in rapid prototyping phase. This new approach will enable to analyze, how the modularization and CE implementation simultaneously could impact efficiency for the rapid prototyping result. For that reason CE methodology is also used in current case-studies and its effects analyzed.

Thirdly, important role from key performance criteria point of view is the skill to prevent RP "bottlenecks" in future development works. Therefore, problems with prototype accuracy and strength have been also investigated and conclusions for problems elimination proposed. Different case studies have been conducted in our research in order to propose the method for improving RP process. Increasing innovation capacity in development of casing type details is needed for ensuring RP sustainability and rapid product development based on RFID reader housing and Smart Dust housing development case studies have been investigated for proposing key performance criteria for better new product development.

For conclusion, it can be pointed out, that in experimental part of current study, the first starting point – RP "bottlenecks" prevention possibilities" are analyzed. Based on real case-studies previously stated first 4 activities in chapter 2.3 have been analyzed for making suggestions regarding product development improvement. Thus, additional key-drivers for Estonian SMEs will be proposed for achieving higher innovation capacity via RP "bottlenecks" prevention.

3.1 RFID Reader's Housing Development

The first case study lies on RFID Reader´s Housing development, where CE implementation is implemented for enabling to carry out product concept, prototyping and product testing phases simultaneously. It will be analyzed how CE implementation already in the beginning of product development phases could own important effect for project success.

Design of complex engineering systems is increasingly becoming a collaborative task among designers, mechanical engineers, IT programmers and electronic engineers. The complexity of modern products means that a single designer or design team can no longer manage the complete product development effort [Sriram, 2006]. Therefore, in this research it has been concentrated onto use of RP as a tool for increasing innovation capacity merging it with new decomposition approach taking into account concurrent engineering, modularization and competences management.

This case study concerns the development of casing type details of Radio Frequency Identification (RFID) reader. The main goal of the device is to monitor (independently from process control) real usage of machines, tools and half-finished products during manufacturing cycle and, based on analyze of collected data, to improve productivity and simplify resource sharing. The target was to develop a housing that is modularized and compact. As there was also the need for cooling the device the concurrent engineering merging competence of different fields of industry was unavoidable and provided excellent possibilities for investigating CE implementation into rapid prototyping in early product development phase where interdependent technical changes and design for product were carried out at the same time. In addition, modularization was also taken into account for understanding connections between developing part structure and functional requirement of each part, which makes the whole prototyping process moiré effective.

3.1.1 Concurrent Engineering in RFID Reader's Housing Development

The whole process of rapid prototyping consisted of different actions from different areas like electronic, thermal and design engineering. In many times RP process efficiency depended on simultaneous works. Therefore, there exists the idea to implement CE also into prototyping process, since according to studies it enables to conduct tasks in product development process in parallel. Thus, the main object was to determine whether it is possible to implement CE also into one PDP phase – rapid prototyping, where conditions of changeable dependent tasks exist. Further, is it possible to handle product concept, prototyping and product tests at the same time and develop prototype simultaneously together with different area engineers in order to shorter prototyping time and thus prevent re-exchanges in prototype in testing phase. For that reason CE was implemented and analyzed.

The whole rapid prototyping process in case of first case study together with concurrent engineering implementation is presented on Figure 3.1.

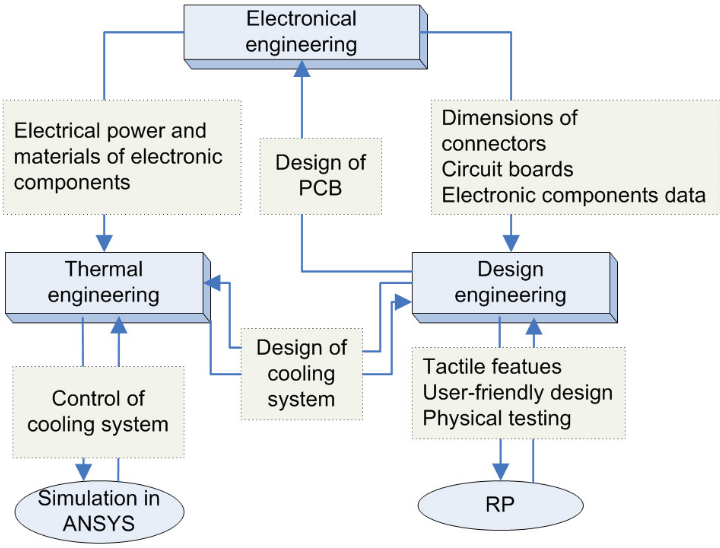


Figure 3.1 Concurrent Engineering in RFID reader's housing prototyping

Electronic engineers of the Department of Electronics at the Tallinn University of Technology (regarding the ELIKO project) provided data of electronic components to thermal engineering and mechanical design engineers, and received recommendations for changing printed circuit board (PCB) configuration to enable safe cooling and dustproof protection. Thus in product concept phase mechanical engineers based on electronic engineers input started to create virtual prototype in parallel activities of electronic engineers. In cooperation with thermal engineers, it was possible to discuss the product design requirements for virtual product. In case some dimensional changes were needed because of the cooling system or circuit board dimension changes, these were discussed between all 3 area engineers. Such collaboration enables the product development process to be quick and effective. Due to simultaneous work by different department counterparties the time for development was decreased. As soon as some technical changes were made by electronic engineers into PCB, the information was communicated also for thermal and design engineers. Design engineers made necessary changes in product design because of PCB dimension changes and thermal engineers continued work with device cooling solution. In case of sequential process every other team-member should have waited until someone makes a new decision for improving or changing the initial concept of product. In addition, some participants should have waited the others to make a suggestion to the first ones and until the changes would have been accepted and implemented by them. In that case, for example, if designers had made suggestions to electronics engineers regarding PCB measurement changes due to better design, they could not have started their implementation because team-members from thermal engineering would also be needed. Only they have knowledge and experience regarding cooling systems and thus only they can decide whether the design changes are relevant regarding device cooling.

Further, virtual tests with prototype were implemented simultaneously in order to make decision points regarding cooling device changes and these changes implementations into virtual prototype. Simultaneous activities between 3 different area engineers have been occupied already in the beginning of product development and it was found that it was possible due to Modularization implementation that is discussed together with virtual prototyping in the following sub-chapters.

Therefore, to emphasize, in a simultaneous engineering process, all anticipations were avoided. All team-members were involved at the same time and all necessary knowledge from all important fields was presented simultaneously during the entire process. Thus, the next decision-making process was easier and less time-consuming in continuous prototyping work. Product concept, prototyping and tests phases were used at the same time due to CE and modularization implementation by different area engineers at the same time in product concept development, prototyping and testing.

3.1.2 Virtual and Physical Prototyping

In development of RFID reader housing prototyping case study virtual and physical prototyping were used. A physical prototype was created by 3D printing technology using Zprinter 310. All RFID reader housing drawings were created with program Solid Edge. It was important to take into account all electronic components and these dimensions already during virtual prototyping. It was often necessary for electronic engineers to change the electronic schematics and thus the whole dimensions of printed circuit board were diminished or new features for fixing components created. Therefore, collaboration of engineers of different specialties was unavoidable and CE implementation added importance for quicker and more efficient prototyping process.

As besides virtual tests (thermal analyze for cooling RFID reader) was done also control tests with physical prototype, physical prototype was also created during the described RP process together CE implementation. For creating a physical prototype from a virtual prototype, all 3D models created with Solid Edge carried STL model. That process enabled the Solid Edge models transmitted into the Zprinter working program for the 3D printing with Zprinter 310. In order to decrease the printing time the printable parts had to be set as optimal as possible with printer program Zprint (see Figure 3.2). It was important for all parts to be located side by side and on one another as much as possible.

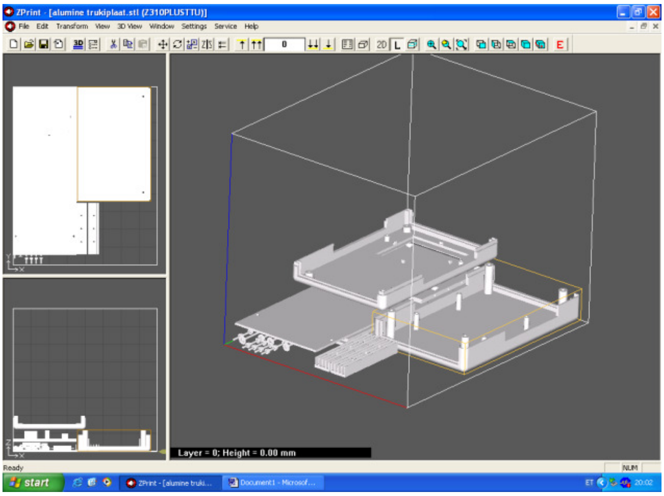


Figure 3.2 Part position for optimal printing

All prototype parts were covered with Cyanoacrylate (Z-Bond 101). When the parts were dry it occurred that they were expanded and the surface structure was changed. The parts did not fit as expected. Therefore, it was necessary to polish and file all parts. That was time-consuming and lead to the understanding that this “bottleneck” should be prevented the next time. Additional analysis had to be carried out and methodology for problem elimination was unavoidable. This problem will be discussed also later in sub-subject 3.2.3 in more detail.

The final RFID reader’s housing physical prototype is presented on Figure 3.3.

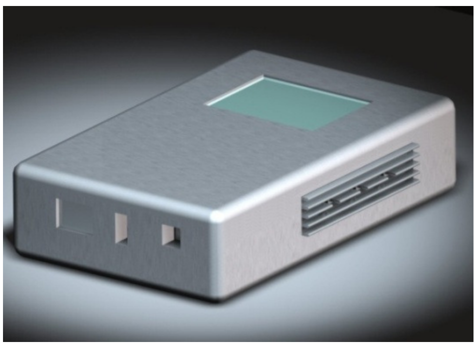


Figure 3.3 RFID reader’s housing

3.1.3 Implementing Modularization into Product Development

As the RFID reader housing had to be easily dismantled and configurable in different kits, modularization was another important key-factor for increasing productivity in rapid prototyping phase in product development. Modular architecture approach was also implemented into RP process, where CE was used. It enabled to contain one-to-one mapping from functional elements to parts and to define different interfaces between parts. Decomposing the product into modules enabled flexibility not only for product developer but also for the final product producer.

The main function of the product was connected with other product part functions and physical properties. Together it is defined as product function structure. Thus, the functional structure for casing of electronic device was created and it is shown on Figure 3.4.

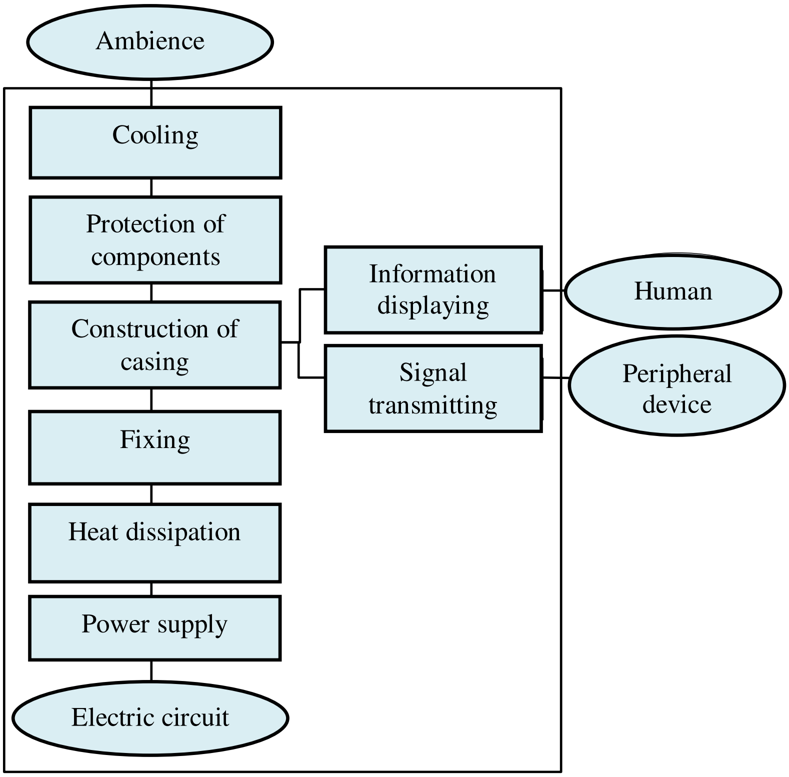


Figure 3.4 Functional structure of electronic device

Many authors have defined functional elements as functional requirements, descriptions, schematics etc [Koufteros, Vonderemse, Doll, 2002]. Due to drawing up functional structure position of functional elements it was easy to understand all requirements for product parts. Electronic device drawings were defined based on product manufacturing needs where functional requirements were taken into account and they played an important role in prototyping. Therefore, defining product parts based on functional elements schematics was important for defining product architecture. In modularization each product part can include one or more different functional elements. Based on modular structure each functional element can be placed into independent module that includes strictly defined interfaces with other modules. Due to these reasons the modularization was implemented in RFID reader's housing development. This enabled to make changes in module without affecting other modules. Thus, the modules were created and developed independently from other systems and CE was possible between different area engineers in different product development phase at the same time.

3.1.4 Thermal Analysis for Cooling RFID Reader

As one of the developing product requirement was also the cooling of device in cooperation with thermal engineers, electronic engineers and designers the cooling solution for the device was also developed in current rapid prototyping process.

The solution consists of two heat sinks and aluminum plate that had to transfer the heat from the warming printed circuit to the ambience. In order to be sure in its reliability, the developed cooling system was calculated firstly by the computer-aided engineering (CAE) analysis program ANSYS. The warming printed circuit board, aluminum plate and heat sinks were defined in the program ANSYS and the properties of materials were determined. According to the calculation results of the simulation program the developed cooling method was suitable for heat rejection from the RFID reader. The biggest quantity of heat occurred on the printed circuit, 0.662 W/mm2 from where by the aluminum plate it was lead to the heat sinks and from there in turn out of device. According to Figure 3.5 simulations confirmed that the developed cooling device assures the heat flow from the device.

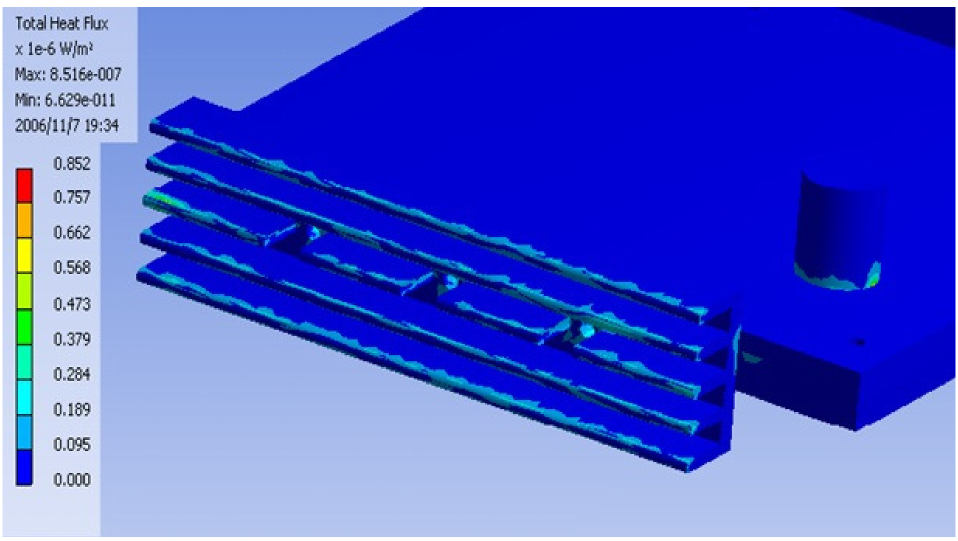
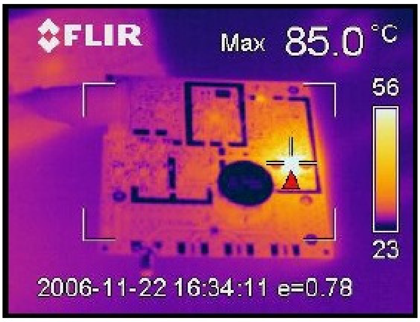


Figure 3.5 Thermal dissipation from the heat sink

3.1.5 Rapid Prototyping Model and its Testing

Finally, a whole set of housing, cooling and PCB was built as RP model. The tactile features of the assembly were tested and thereafter PCB and heating replaced with real components. To test the developed cooling system and to be sure that the device does not overheat, other tests with thermal camera Thermo CAM E45 with uncertainty of measurement 0,1ºC were performed with RP model.

At first, it was measured to what extent the printed circuit became warmer without cooling. Within 30 seconds PCB temperature raised up to 85 ºC. Figure 3.6 shows the measurement results without cooling (a) and with cooling (b).



a) without cooling

b) with cooling

Figure 3.6 Temperature raise of PCB

After the PCB temperature was measured again with developed cooling solution during the first 30 seconds, temperature raised and then stabilized on 58,6 ºC. Viewing the temperature distribution from the other side of printed circuit board covered with aluminum plate, it was noted that the heat dissipation was homogeneous and extended over the surface to the heat sinks. The maximum temperature on the aluminum plate was 32,0 ºC (see Figure 3.7).

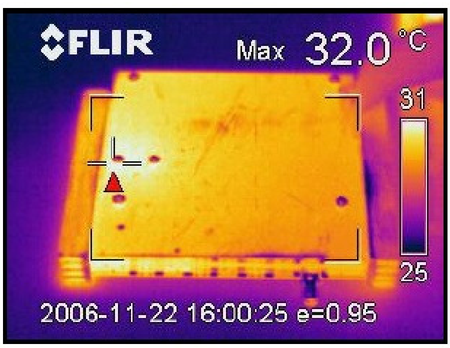


Figure 3.7 Homogeneous heat dissipation

Hereby, without cooling printed circuit's temperature raised in 30 seconds at the maximum level up to the 85 degrees, with cooling it stabilized on 58,6 degrees. The rest of heat was led to the aluminum plate and from there in turn to the heat sinks. Therefore, measurements proved that homogeneous heat dissipation was guaranteed with developed cooling method and device will be cooled with the proposed cooling solution. Thus it can be said, that the co-operational rapid prototyping project for RFID reader has been successful. With different area engineers simultaneous activities it was possible to reach to the successful prototype. Due to modularization approach implementation it was possible to prototype product parts in different modules and thus to do co-operation between different area engineers more efficiently at the same time.

3.2 Smart Dust Housing Development

The second case study lies on Smart Dust Housing Development. During this case study main "bottlenecks" of RP from earlier practice have been also occurred and therefore will be investigated and analyzed in more detail. Thus it was necessary to find main key-drivers, how to improve RP process in order to improve enterprises innovation capacity via RP process efficiency. As also in case of RFID reader housing development in prototyping phase accuracy problem occurred, the same issue is viewed with higher importance in case of smart dust housing development.

This case study concerns the development of casing type details of Smart Dust. Distributed computing solutions based on miniature computing devices called "smart dust" were introduced at the beginning of this century. The sensors are integrated into small sized boards and equipped with small sized accumulators, because of autonomous power supply and wireless communication interface the deployment of these systems is simple, relatively cheap and fast – integration with existing equipment is possible with little effort. For industrial applications the size of the sensor board is not critical, and therefore it enables to increase the size of energizer allowing maintenance free operation. The modularized test network model was built at the Tallinn University of Technology [Preden, 2007]. To realize the network suitable for machinery workshop environment all motes had to be protected with housings. Therefore, one of the main aims of the second case study was to analyze modularization of smart dust housing and build up modularized smart dust platform. Secondly, the rapid prototype for smart dust housing had to be developed.

3.2.1 Modularization of Smart Dust Housing

The main aim of the second case study was to analyze functions of all motes in order to find out the common set of functions for basic smart dust product platform. The possibility was found to create a modularized smart dust platform. Such a platform consists of common modules and unique modules, which will be needed for creating new smart dust product configurations. It will lead to reuse of common modules. Thus, interactions between modules were determined according to the type and strength. The modular platform for smart dust and interactions between the modules are presented on Figure 3.8.

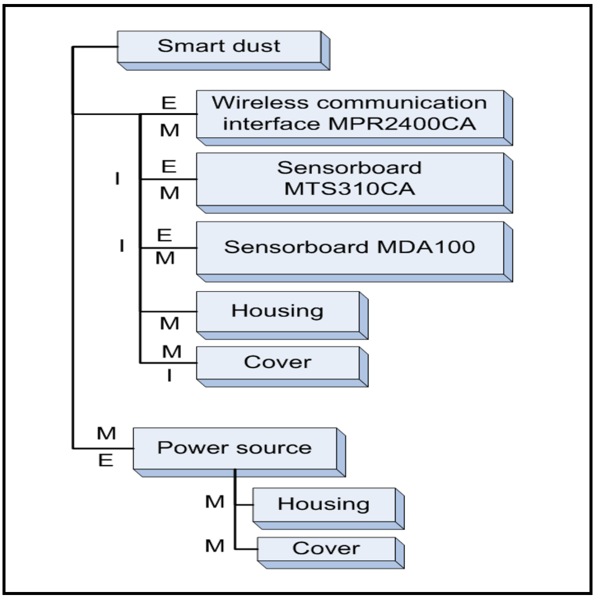


Figure 3.8 Modular platform and interactions between the modules

Interaction types are the following: M – mechanical, I – informational and E – electrical.

Modularized platform architecture showed us module types and relations between modules and wireless communication interface. The platform architecture simplified selection, allowed combining suitable modules and varying them during the creation of new smart dust configuration. Based on modularization information the housing for product was created. The circuit boards were fitted inside the housing. The cover for sensors depended on configuration and was always changeable.

The power source had its own housing (see Figure 3.9). The size of this housing depended on used power cells. The modular structure enabled changing of different modules without affecting others. It means that the power source can be changed to different elements when necessary.

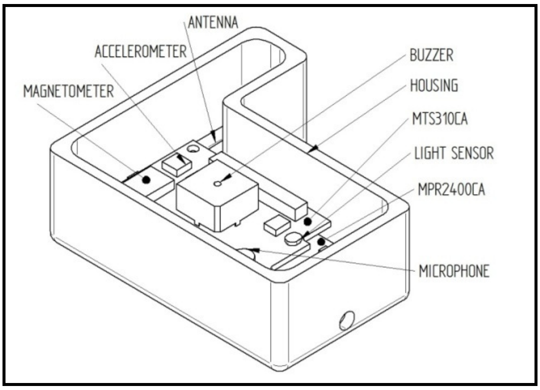


Figure 3.9 CAD model of housing for smart dust (cover is not shown)

3.2.2 Rapid Prototyping for Smart Dust Housing

The aim was to produce a prototype of this housing for smart dust. It is already known that rapid prototyping can be realized in different methods. One possibility used also in previous case study is an inkjet printing system. Layers of fine powder are selectively bonded by "printing" a water-based adhesive from the inkjet print head in the shape of each cross-section as determined by a CAD file. It is also advertised as the fastest method.

Another method for rapid prototyping used was Fused Deposition Modeling (FDM) that uses a nozzle to deposit molten polymer onto a support structure, layer by layer. Therefore, in this case study we decided to compare Inkjet Printing Technology (IPT) with Soluble Support Technology (SST) printing - in the latter the Dimension SST 3D printer was used. Therefore, prototype was made by using the same technology that was used for RFID reader prototyping (inkjet printing) and also by using soluble support technology. It was necessary for analyzing the accuracy problem that has been occurred in case of RFID reader housing prototyping with Inkjet Printing.

The Dimension SST (Soluble Support Technology) incorporates the same technology as the original Dimension BST (Breakaway Support Technology) and therefore produces the same high-quality 3D models. The difference is that Dimension SST features an automated support removal process. The designer can simply remove the model from the system and place it into an SST Station. An SST Station is an agitation system that utilizes hot water and a soap bath to automatically wash away the support structures. Essentially, the Dimension SST enables "hands free" printing.

After the prototype was created by applying these two technologies, it appeared that each technology has its advantages and disadvantages. Generally, the main considerations in RP are speed, cost of the printed prototype, cost of the 3D printer, choice of materials, color capabilities, etc. We decided to make a prototype of smart dust housing by using both technologies in order to understand in which cases both of them can be implemented in the future product developments. In addition, coordinate measurement machine TESA Micro-Hite 3D was also used for deciding which of the two, IPT and SST 3D printing technologies is more up in grade, timesaving and effective. Thus, the housings of smart dust were printed with both 3D printing technologies and the dimensions of housings were measured and analyzed for investigating prototyped parts accuracy problem in more detail. The measurement results of physical and virtual prototype dimensions together with main findings are presented in the following chapter 3.2.3 in more detail.

3.2.3 Uncertainty of Arithmetic Means of Physical Prototype Dimensions from Virtual Prototype Dimensions

In recent years three-dimensional printing (3DP) has emerged as a very competitive process in terms of cost and speed, and sales of related equipment have increased significantly compared to the other RP machines [Wohlers, 2005]. Although it is spreading rapidly worldwide and it is one of the most widely used layered manufacturing equipment, an accuracy problem has been detected. It is remarkable how the question of accuracy in most successful case studies is carefully avoided. Recently, the accuracy problem was analyzed and it has been pointed out that the accuracy of the printed models is influenced by the following three factors [Dimitrov, 2006]:

1. material (powder) used to produce the item;
2. 3D printer axis responsible for the particular dimension, and;
3. magnitude of nominal dimensions.

On the one hand, rapid prototyping has emerged as a key enabling technology with its ability to shorten product development and manufacturing time. But on the other hand, it is not allowed to forget the question of accuracy.

It was noticed already in the first case study that after 3D printing the part measurements differed between virtual and physical prototype dimensions. In case of inkjet printing technology, after-treatment for printed parts was needed and in some cases parts did not fit together. In order to prevent such problem in the future in product rapid prototyping we decided to print smart dust housing detail by using two different 3D printers and compare those measurements differences between virtual and physical prototype dimensions. Therefore, smart dust housing prototype was made twice by using inkjet printing and soluble support technology. After that both prototype's all dimensions were measured with coordinate measurement machine TESA Micro-Hite 3D fifty times and comparative analysis was made. Measured dimensions of smart dust housings are presented on the Figure 3.10.

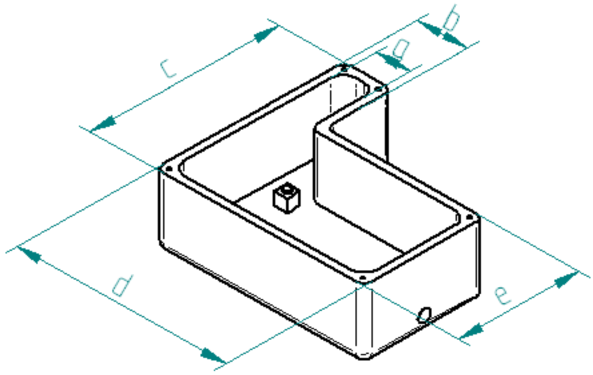


Figure 3.10 Measured dimensions (a, b, c, d, e) of smart dust housing in comparative 3D printing

Both prototypes' (IPT and SST) measurement results were analyzed with program Excel. In order to find uncertainty of arithmetic mean of physical prototype dimensions from virtual prototype dimensions, the following calculations need to be conducted:

1. Arithmetic means for measurement results were calculated in case of all dimension IDs.

$$y = \bar{x}_i = \frac{1}{n_i} \sum_{j=1}^{n_i} x_{ij} \qquad (3.1)$$

In Table 3.1 virtual prototype dimensions are presented together with arithmetic means of physical prototype dimensions.

Table 3.1 Smart dust housing dimensions (mm)

Dimension ID	Virtual prototype (CAD) dimension	Arithmetic means of physical prototype dimension	
		IPT	SST
a	13,0	0,06	0,01
b	19,0	0,33	0,10
c	72,0	0,32	0,81
d	80,0	0,22	0,03
e	46,0	0,31	0,91

2. Measures and experimental dispersion

$$s^2(x_{ij}) = \frac{1}{n_i - 1} \sum_{j=1}^{n_i} (x_{ij} - \overline{x_\iota})^2 \tag{3.2}$$

where n_i – number of measurands,
x_{ij} – weighting factors,
$\overline{x_\iota}$ – arithmetic mean

3. Experimental standard deviation

$$s(x_{ij}) = \sqrt{s^2(x_{ij})} \tag{3.3}$$

4. The variance of arithmetic mean

$$s^2(\overline{x_\iota}) = \frac{1}{n_i(n_i - 1)} \sum_{j=1}^{n_i} (x_{ij} - \overline{x_\iota})^2 \tag{3.4}$$

5. Standard uncertainty of measurement

$$s\,(\overline{x_\iota}) = \frac{s\,(x_{ij})}{\sqrt{n_i}} \tag{3.5}$$

Measurement calculation results are presented in the following table (see Table 3.2).

Table 3.2 Measurement calculation results (mm)

IPT					
Dimension ID	$\overline{x}_i$	$\sum(x_{ij} - \bar{x}_i)^2$/ mm²	$s^2\,(x_{ij})$	$s(x_{ij})$	$s(\overline{x}_i)$
a	0,060	0,461	0,009	0,097	0,014
b	0,330	0,005	0	0,010	0,001
c	0,320	0,015	0	0,017	0,002
d	0,218	0	0	0,003	0
e	0,308	0,005	0	0,010	0,001

Table 3.2 continuation

SST					
Dimension ID	$\bar{x}_i$	$\sum(x_{ij} - \bar{x}_i)^2$ / mm^2	$s^2(x_{ij})$	$s(x_{ij})$	$s(\bar{x}_i)$
a	0,012	0,101	0,002	0,046	0,007
b	0,103	0,016	0	0,017	0,002
c	0,810	0,026	0,001	0,022	0,003
d	0,031	0,005	0	0,010	0,001
e	0,909	0	0	0,002	0

6. Uncertainty component of measurement device

$$u_{instrument}(m) = \frac{deviation\ value}{\sqrt{3}} \qquad (3.6)$$

As coordinate measurement machine TESA MicroHite 3D distribution value is 1цm, the uncertainty component appears:

$$u_{instrument}(m) = \frac{0{,}01}{\sqrt{3}} = 0{,}006 \text{ mm}$$

7. Uncertainty of measurement

$$u(y) = \sqrt{s^2(\bar{x}_i) + u^2(m)} \qquad (3.7)$$

Table 3.3 Uncertainty of measurement results (mm)

Dimension ID	IPT	SST
	measurement results *u(y)*	
a	0,015	0,009
b	0,006	0,006
c	0,006	0,007
d	0,006	0,006
e	0,006	0,006

Finally, it was possible to present dimension ID-s measurement results with 95% certainty (k=2) with the following formula:

$$y = \bar{x}_i \pm k\ x\ u(y) \qquad (3.8)$$

Measurement results with 95% certainty (k=2) are presented in Table 3.4 and present uncertainty of arithmetic mean of physical prototype dimensions in case of using IPT and SST prototyping technologies.

Table 3.4 Uncertainty of arithmetic means of physical prototype dimensions (mm)

Dimension ID	IPT	SST
a	y=0,06±0,01	y=0,01±0,01
b	y=0,33±0,01	y=0,10±0,01
c	y=0,32±0,01	y=0,81±0,01
d	y=0,22±0,01	y=0,03±0,01
e	y=0,31±0,01	y=0,91±0,01

Consequently, this smart dust housing development case study helped us to find the uncertainty of arithmetic mean of physical prototype dimensions in case of 3D printing by using IPT and SST technology. It came out that the error of SST printing was bigger in case of c and e dimensions. It makes reference to the circumstances that SST printing error is bigger in one direction (c, e) printing and smaller in other direction (a, b, d).

From the timesaving point of view, the inkjet printing technology enabled to print the smart dust housing in 1 hour and 10 minutes, SST printing in 3 hours and 23 minutes. According to this study the inkjet printing technology is more efficient. Still, it is important to consider that inkjet printing requires mechanical after treatment, which is not necessary with SST printing technology. Also, the quality of printing was better with SST printing.

Altogether it can be said that for better comparison of printing technologies more criteria should be considered for making the final comparison. In addition, another experiment with arithmetic means of printed part (physical prototype) dimensions should be implemented. For the above mentioned reasons the next chapter deals with comparison of different RP technologies and analyses printed part dimensions also in case of another housing development.

3.3 Comparison of Rapid Prototyping Technologies

Previously two different RP machines were used in new product development case studies where RFID and smart dust housing rapid prototypes were created. In the first case study RFID reader housing RP was created by using Zprinter 310 (Inkjet Printing Technology). In the second case study smart dust housing RP was created by using another RP technology – SST (Soluble Support Technology). In addition, the uncertainty of arithmetic mean of physical prototype dimensions from drawing dimensions (virtual prototype dimensions) were found by comparing IPT and SST printing technologies. After that it was interesting to realize, how the measurements between RFID reader housing virtual and physical prototype dimension can differ. Therefore, another comparison of prototype part measurements was accomplished where RFID reader housing was printed in addition to IPT by using plastic laser sintering technology (PLST). It provided a good possibility to compare three most well-known RP technologies. Thus, following RP machines and technologies were used: Zprinter 310 based on Inkjet Printing Technology (IPT), Dimension SST 768 based on Soluble Support Technology (SST) and Formiga P 100 based on Plastic Laser Sintering Technology (PLST). The comparison of RP technologies was made based on the following criteria:

- uncertainty of arithmetic mean of prototype dimensions from drawing dimensions;
- speed of prototyping;
- quality of prototype (need for mechanical after-treatment);
- preparatory works (e.g. 3D models need to be carried into stereo lithography tessellation language (STL) model);
- physical properties of materials.

The uncertainties of arithmetic mean of prototype dimensions were already investigated in case of smart dust housing RP that was printed out by using IPT and SST. For further research prototypes created by using IPT and PLST technologies were investigated from the point of view of uncertainties of arithmetic means of prototype. Therefore, another RP for RFID reader housing was made by using PLST technology. Prototype dimensions that are presented on Figure 3.4 were measured fifty times with the coordinate measurement machine TESA Micro-Hite 3D.

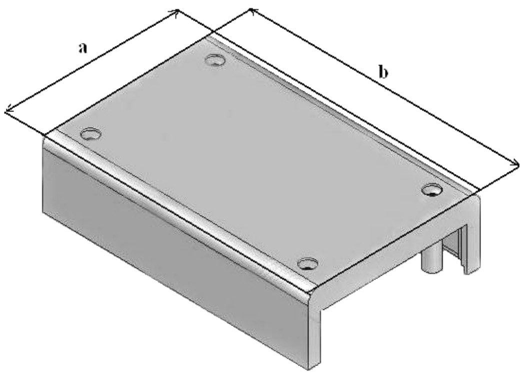


Figure 3.11 Measured dimensions (a, b) of RFID housing

Thus it was possible to compare measurements differences of printed part dimensions also in case of IPT and PLST. In Table 3.5 arithmetic mean for RFID reader housing dimension ID-s is presented that was calculated by using relation (3.1). In addition, virtual prototype (CAD) dimensions are presented.

Table 3.5 RFID reader housing dimensions (mm)

Dimension ID	Virtual prototype (CAD) dimension	Arithmetic mean of physical prototype dimension	
		IPT	PLST
a	96	0,78	0,37
b	174	0,43	0,18

Based on same calculations that were implemented for smart dust housing dimensions comparative analyze, arithmetic mean in case of IPT and PLST were investigated. Measurement calculation results are presented in Table 3.6.

Table 3.6 Measurement calculation results (mm)

IPT					
Dimension ID	$\bar{x}_i$	$\sum(x_{ij}-\bar{x}_i)^2/$ mm^2	$s^2(x_{ij})$	$s(x_{ij})$	$s(\bar{x}_i)$
a	0,781	0	0	0,002	0
b	0,431	0	0	0,002	0
PLST					
Dimension ID	$\bar{x}_i$	$\sum(x_{ij}-\bar{x}_i)^2/$ mm^2	$s^2(x_{ij})$	$s(x_{ij})$	$s(\bar{x}_i)$
a	0,370	0	0	0,002	0
b	0,180	0	0	0,001	0

As all part dimensions were measured also with coordinate measurement machine TESA MicroHite 3D, the uncertainty component was also 0.006 mm and uncertainty of measurement calculable with formula 3.7. The results are presented in Table 3.7.

Table 3.7 Uncertainty of measurement results (mm)

Dimension ID	IPT	PLST
	measurement results $u(y)$	
a	0,006	0,006
b	0,006	0,006

By taking into account uncertainty of measurements, the measurement results for RFID reader housing dimensions can be presented as follows.

Table 3.8 Uncertainty of arithmetic mean of physical prototype dimensions (mm)

Dimension ID	IPT	PLST
a	y=0,78±0,01	y=0,37±0,01
b	y=0,43±0,01	y=0,18±0,01

It occurred that in case of Zprinter 310 the uncertainty of arithmetic means of physical prototype dimensions was greater in both directions (a, b). As a result of comparison of Zprinter and Dimension SST 768 (see Table 3.4) it can be stated that the uncertainty of the first one was greater in directions a, b and d. It shows that the uncertainty of arithmetic mean of physical prototype dimensions is mostly worst in case of Inkjet Printing Technology.

In order to give a better overview about comparison results they are presented in the table where another comparison criterion that has been listed at the beginning of the chapter is also taken into account. Thus, the results of RP technologies comparison are presented in Table 3.9.

Even though the prototyping time is the shortest with Zprinter 310, it is not a good idea to use it in case of high accuracy requirements because of the biggest uncertainties of arithmetic mean of physical prototype dimensions from virtual prototype (CAD) dimensions. As preparatory work was conducted in case of all three printers, using IPT technology required the most complicated after-treatment. However, the PLST required only cooling after the printing process, any after-treatment was not necessary.

This comparative table is useful for future development where the suitable RP technology can be selected taking into account different preconditions that can be related to the comparison criteria from the prepared table. Right technology selection helps to prevent unexpected results during and after the prototyping process.

Table 3.9 Comparison of RP technologies (IPT, SST, PLST)

Estimation criteria	Prototyping technology (including device name)		
	IPT (Zprinter 310)	SST (Dimension SST 768)	PLST (Formiga P 100)
Uncertainty of arithmetic of physical prototype dimensions from virtual prototype dimensions	Compared IPT with SST in one direction (a, b, d) the IPT uncertainties of arithmetic mean in 3D printing results is bigger than another directions (c, e)		
	Compared IPT with PLST the IPT uncertainties of arithmetic mean in 3D printing results is much bigger than in case of PLST		
Speed of prototyping	1 hour 10 minutes (smart dust housings detail) not including: - covering with glue - drying with compressed air	3 hours 23 minutes (smart dust housings detail) not including: - SST Station	
	30 minutes (RFID reader housings detail) not including: - covering with glue - drying with compressed air - mechanical treatment		8 hours and 6 minutes (RFID reader housings detail) not including: - cooling
Quality of prototype	poor	good	excellent
Preparatory works	3D model into STL model; parts optimal setting	3D model into STL model	3D model into STL model; check over of parts
After treatments	Need for mechanical after treatment (polish and file of parts)	SST Station for automatically wash away the support structures	-
Cost of prototype	Low	Low	High
Cost of prototyping device	Low	Average	High
Choice of materials	Fine powder and special glue (Cyanoacrylate (Z-Bond 101))	Fine powder and molten polymer	Fine powder

3.4 Tensile Strength Analysis

In addition for accuracy problem investigation, based on real case studies it was possible to analyze also the printable part positioning influence to the strength of prototype. In lately described case studies test with prototyped parts have been done and in some cases there was need to handle these part very carefully in order to not let them broken. For that reason it was occurred that in addition to previously listed comparison criteria, it is also necessary to know the prototype strength. In many cases it might be necessary to use the prototype in product assembly and therefore it has to be sufficiently strong. In addition, the prototype has to be resistant for transportation or different experiments. Therefore, the strength of the prototype in current study was also investigated.

The physical properties of the materials used in three-dimensional printing were unknown and therefore several tests were conducted to find out the modulus of elasticity, extension at break, tensile strength of the material and investigated how infiltrating the part with z-Bond resin affects these properties. Physical properties of the part depend on the level of attrition on the printing head, bonding material, orientation of the part during printing and how the part is post processed.

The shape (shown on Figure 3.12) of the test specimen was identical to the ones used in steel or aluminum tensile tests [Noorani, 2006].

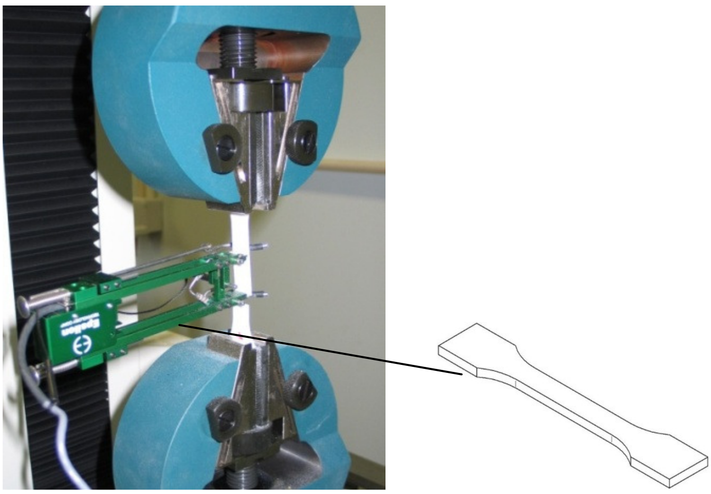


Figure 3.12 Test specimen and its measurement set-up

During the experiment forty test specimens were printed by using Zprinter 310 (IPT) and 20 test specimens by using Formiga P 100 (PLST). The test specimens printed using IPT were divided into four groups, including 10 test specimens in each group. The first group of test specimens was set up in an upright position and had no post processing. The second group was set horizontally and had no post processing. Third group was set up in an upright position but was infiltrated with z-Bond resin. The fourth group was placed horizontally and also infiltrated with z-Bond resin. Test specimens printed using PLST were divided into 2 groups because they did not need post processing. The first group was set in an upright position and the second group was positioned horizontally.

The experiment was conducted with tensile strength testing machine H10KT-0210 and extensometer Epsilon ST where all groups test specimens were included. Experiment data that were used in case of upright position printed part was the following: load range 10000 N; extension range 300 mm; gauge length 72 mm; speed 5 mm/min; approach speed 0.3 mm/min and preload 0 N. In case of horizontally printed part: load range 10000 N; extension range 2000 mm; speed 10 mm/min; approach speed 1,6 mm/min and preload 0 N.

The average results that have been found by taking into account EN ISO 527-1 are presented in Table 3.10.

Table 3.10 Test results

	IPT			PLST		
	Force (N)	Tensile strength (MPa)	Extension at break (%)	Force (N)	Tensile strength (MPa)	Extension at break (%)
	Upright positioning, no post processing					
Average	21,3	0,591	0,109	2025	50,6	9,80
	Horizontal positioning, no post processing					
Average	58,2	1,617	0,091	2210	53,2	16,63
	Upright positioning, post processed					
Average	271,1	7,532	0,261			
	Horizontal positioning, post processed					
Average	218,4	6,066	0,391			

By specifying the test specimen area of cross section it was possible to find out the average force necessary to exert in order to break the printed part. Therefore, tensile strength calculations with tensile strength testing machine were calculated and average extensions at break (%) measured with extensometer. The tensile strength analysis demonstrates the part power of resistance until breakage, the elongation of the part and the amount of stress before breakage. Extension at break (%) demonstrates the extent of elongation from the part original length and shows how much the part can be stretched before breaking. Therefore, knowing the force required to break the printed part it is possible to calculate stress values in the printed part. That means it is possible to add or remove material from less stressed places of the part and thus optimize the printing process and the part itself. According to the experiment the results varied greatly between the different groups of test specimens.

The groups printed using IPT that had post processing with z-Bond resin (groups 3 and 4) had a higher tensile strength. The average tensile strength was higher by 5,7 MPa in groups with no post processing. Elongation was higher in groups 3 and 4 by 0,23%. According to the results the part orientation during printing and post processing are essential.

The groups printed using PLST had no post processing, thus they can only be compared with the first two groups of IPT. Tensile strength of materials is substantially higher, on average 50,8 MPa and extension at break by 13,1% (on average), that is much higher than on IPT.

Therefore, comparing test groups with groups that were post processed, group three (orientated in an upright position) had better results than group four (orientated horizontally). The reason for it is that group 3 specimens had more layers. Resin infiltrates deeper into the part between the layers thus creating a stronger part. The disadvantage of more layers is higher surface roughness. In some cases it is useless because the part has to look esthetic and presentable. It can be solved by sanding the surface but it reduces the accuracy of the part.

According to the tests most of the IPT part's strength comes from the resin. The level of resin infiltration depends on the powder and positioning of the part. Resin infiltrates deeper into the part when it is positioned upright in the printer building area. It means that by right positioning and considering the resin's properties, modifications to the parts can/should be made.

PLST on the other hand had more consistent results. Tensile strength was affected but not so much by changing the orientation of the parts. Extension at break was lower on the parts in upright position because the pulling force was perpendicular to the layers direction.

To sum up, it is necessary to know that the orientation of printable parts influences the detail tensile strength, especially in case it is printed by using inkjet printing technology. In case of plastic laser sintering technology the differences between horizontal and upright positioning are not so noticeable, but are essential, when the part strength owns special attention. On the other hand, the results are useful for optimizing the printing process and the part itself. It refers to the possibility to add or remove material from less stressed places of the printable part.

3.5 Conclusions of the Chapter

As previous investigations regarding RP quality do not present solutions for preventing RP „bottlenecks“, it was necessary to deal with the problem of prototype accuracy with greater care. Thus, one main researched problem was the comparison of part measurements differences between virtual and physical prototype dimensions. Two case studies (smart dust housing and RFID reader) were carried out in order to compare IPT versus SST and IPT versus PLST. Uncertainty of arithmetic mean of prototype dimensions was calculated and conclusions for physical and virtual prototype dimension variation prevention proposed.

Secondly, as RP spreads rapidly worldwide and it is one of the most widely used layered manufacturing equipment, it was important to know pros and cons of different RP technologies. Different RP technologies Implementation of RP technologies in real case studies gave the possibility to analyze IPT, PLST and SST technologies in more detail and therefore the comparison of these three RP methods was made and presented in Table 3.9. This comparative table of IPT; PLST and SST technologies including common important criteria is a useful support material for making the right decisions in RP technology decision-making process.

Thirdly, concurrent engineering and modularization principles were implemented into RFID reader and smart dust housing rapid prototyping process for investigating its influence already at the beginning of the product development processes. A lot has been written about CE and modularization. It has been done mainly from the product development process point of view where CE has an important effect on simultaneous work, e.g. for enterprise production department, marketing and sales department. Modularization, however, is viewed from the standpoint where all functions are related to different modules for enabling easy changes of faulty parts in product assembly during the guarantee period. In current study CE and modularization were implemented already in the product concept, RP and testing phases and it was investigated that this approach has positive effects for more effective collaboration already at the beginning of the product development process. It was found that it is not important to use CE for simultaneous activities in marketing and producing phases, but it is necessary to involve it already in the beginning of product development processes, where modularization involvement in one´s turn enables to make the cooperation between different compartments more effective. .

Finally, the printing results improvement possibilities were investigated from the point of view of printed part physical properties and positioning. Sixty test specimens were printed with IPT and PLST technology and experiments in different test groups with tensile strength testing machine and extensometer were conducted. Proposals for printable part optimization and strength rising were made.

Altogether it can be said, that “bottlenecks” that occurred earlier in our RP practice were all investigated and it was discovered how to avoid these problems in future RP process:

1. It is possible to avoid the differences between physical and virtual prototypes dimensions. In order to avoid the situation where the RP part (physical prototype) dimensions are not the same as CAD (virtual prototype) dimensions, it is important to know the uncertainty of arithmetic mean of physical prototype dimensions from virtual prototype dimensions. It gives designers and engineers the possibility to minimize the virtual prototype’s

(CAD) dimensions before the RP process (physical prototyping). Therefore, a problem in differences between physical prototypes compared to virtual prototype can be diminished by using comparative pre-testing that have been worked out in current study.

2. Comparative table of 3 RP technologies can be used as back-up material for making the right decisions regarding rapid prototyping technology selections. It enables to prevent unexpected results during and after the RP process. For example, it has an important effect not only on prototype quality but also on product development speed.
    - If the accuracy of RP is essential it is important to know that in case of IPT uncertainty of arithmetic mean was higher in case of all prototype dimensions. Therefore, without pre-testing that enables to avoid differences between physical and virtual prototype dimensions, the part accuracy is the worst of the three compared technologies.
    - Printing speed was the best in case of IPT but it has to be reminded that in case of this technology after treatment is unavoidable and inconvenient. All parts have to be separately covered with special glue and dried with compressed air. In addition, mechanical after-treatment is also needed in order to improve the quality of surface.
    - In case of PLST after treatment means only cooling after the printing process.
3. Since in handled case studies (RFID reader and smart dust housing development) it was necessary to conduct additional changes during rapid prototyping process, modularization and CE were used in practice in order to reach to final objective more easily. It was resulted based on handled case study, that positive effects for improving collaboration and making the RP process more effective are the following:
    - In case of RFID reader housing development CE enabled to make necessary changes in product concept simultaneously with prototype development and virtual tests. It means that if the product concept changed during prototyping and testing process, it was possible to be simultaneously flexible regarding the product design due to modularization implementation at the same time. PD continued at the same time when one part of the team came across with some technical changes and the other part toolkit simultaneously into account and proposed a new suitable product design and test the whole concept with virtual prototype. Therefore, the overall time spent on design and manufacture prototype and new product can be substantially reduced, if more than one activity is conducted simultaneously rather than in series already in the beginning of product development phases. It was resulted that modularization involvement into CE

conceptual model enables to makes the whole process due to different modules handling more effective.

- Modularization has positive effect not only from the point of view of production but also rapid prototyping. Based on theory modular structure each functional element can be placed into independent module, which includes strictly defined interfaces with other modules. It was resulted that this approach is not useful not only for production and failure product detail changes but also enables to make changes in prototype component without affecting other assembly elements. Therefore, case studies showed that modularization approach is also suitable for apparatus industry in product development first phases, where already during the prototyping the variety of functions in electronic device can lead to need for changes and can be easily changed due to CE methodology usage. Therefore it was found, that modules should be taken into account together with CE process already in product concept, prototyping and test phases that enables changes in prototype independently from the other assembly at the same time with other continuous activities.

4. Positioning the parts during printing (IPT) influences physical properties of the parts. Upright positioning with post processing increases the maximum tensile strength about eight times and extension at break about three times. Therefore, in case of IPT, it is possible to increase part tensile strength by positioning the printable part in printing process upright position.
   Using PLST, positioning the parts affects only the extension at break. It is increased about two times by positioning the part horizontally compared to upright positioning. The tensile strength and extension at break were substantially higher in PLST than in IPT. Therefore, when the strength of prototype is essential, the RP technology PLST should be preferred.

To sum up, to prevent RP “bottlenecks” the suggestions are the following:

- Use comparative pre-testing or its results presented in current work for handling the problem in differences between physical prototypes compared to virtual prototype. It helps to avoid differences between virtual and physical prototypes and does not favor the situation where printed parts do not fit together.
- Take into account comparative table of RP technologies where presented criteria could have an essential effect on RP result(s). Right technology selection helps to avoid unexpected results that might occur during or after RP process.
- For decreasing RP time and thus the whole PDP time and for increasing the development quality CE together with modularization implementation have to be used already in first phases of product

development. Modularization implementation into CE conceptual model enables to make the enterprise product development process more effective. The need for expensive engineering changes after prototype tests and also time and costs for whole development process can be decreased.

- Involve different methods in testing and implement control-tests. Simulation utilization and additional testing with RP models confirmed that such approach enables to prevent product failures later. Additional analyses gave strength to the developed solution and can easily help engineers to find out the bottlenecks that need to be additionally improved before the production.
- Take into account tensile strength analysis results when strength of RP is essential, because positioning the parts during printing influences physical properties of the parts.

Case studies as experiences of product development confirmed that production cost and time could be reduced, when RP “bottlenecks” are prevented. Therefore, learning from the previously listed results is unavoidable and essential for better results in the future in product development.

4 CAPACITY ANALYSIS

It is known, that the imperative to innovate successfully is assuming greater importance due to the increasingly rapid technological change and associated market instability as well as increasing demands from customers for innovative and better products. In the meantime the convergence of multiple discrete technologies and main changes in the competitive landscape are offering greater opportunities for innovation [Prahad, Ramaswarmy, 2004].

Thus, the definition of innovation has changed over the years and it was pointed out that the definitions of innovation share two important attributes [O`Regan, Ghobadian, 2006]. Firstly, any innovation involves "change". Secondly, innovation has to have a positive end product. Most definitions of innovation are concerned with identifying and using opportunities to create new products/services or work practices. But innovation concept today is more than new product development. It also encompasses process and management practices and applies to services as well as products and it applies to firms and industry sectors. Furthermore, there is a new broad view of the innovation process – it is essential and necessary for organizations to deal with educational dimensions of innovation. Nowadays it is often not enough when firms focus only on R&D and on the technological aspects of innovation [Lundvall, 2007]. Thus, organization's chiefs not only have to provide physical capital (R&D and technology infrastructure) but should also deal with enhancing human capital (training of workers) and social capital (i.e. encouraging the formation of trust based relationships between other firms). Therefore, it is more and more important that companies are doing cooperation with other firms or research organizations and universities, as well. It helps to import ideas and knowledge from other organizations and strengthen firm's internal R&D activities.

The influence of innovation to productivity has been so far investigated mainly from the viewpoint of economical science. Intellectual capital has been measured by taking into account a knowledge-based view of the firm and the importance of measuring organizational knowledge assets have been investigated by Marr, Schiuma and Neely in 2004. They have analyzed different methods for storing knowledge inside organization and discovered how it could help to improve sustaining organization knowledge, but have not handled the employee competence influence on human assets and on organization innovation capacity. Thus, there existed the need to investigate enterprise competences in more detail. We took the purpose to investigate employees and entrepreneurs competences in the engineering industry. Competences were analyzed based on categories of special, professional and basic skills/knowledge, taking also into account influence of technological capacity (existing technological resources). Therefore, in the current chapter KPIs in innovation have been handled from the point of view of organization competences. We found, that employees and entrepreneurs in the machinery, metal and apparatus engineering sector are dependent upon competency, which influences also the technological capacity of organization.

Engineering industry enterprises in Estonia are mainly SMEs. There are over 400 small and medium sized enterprises in this sector. In some cases the research among enterprises have shown that enterprises are not very flexible for accepting and enforcing new technological resources and/or production range, and thus can continue their activities ineffectively. Therefore, the main goal was mapping and analyzing of modern typical processes necessary for product development, elaboration of development models for the engineering industry sector and giving corresponding recommendations through web-based expert tool. In this chapter the methodology for mapping innovation potential is described. In experimental part a case study tied with development of networked wireless products/systems development is included. Data about human resources and technological resources are collected and saved into database Innomet. This provides an input for data flow monitoring in industrial processes, concentrating on product development process analysis. The research was concentrated on product/technology development in the sector of engineering industry. As a result, an expert tool for monitoring and increasing innovation capacity in SMEs was developed.

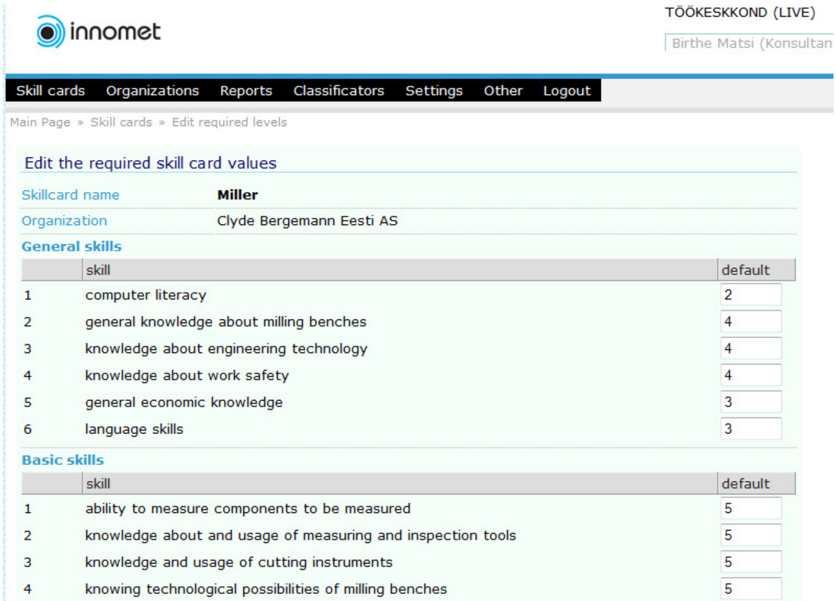
4.1 Monitoring Innovation Capacity at Engineering Industry Enterprises in Estonia

Engineering industry enterprises in Estonia are mainly SME-s and are often specialized in a quite narrow field. Thus, those firms do not have enough resources for all activities necessary for rapid product development. As a consequence, there is often need for outsource R&D. On the other hand, there is need for modularization. The latter enables to develop and produce the compatible product parts separately by different firms.

Describing the general situation in Estonia, it should be noticed that innovative solutions are patented rarely – there were 23 patent applications, and 74 utility model applications by internal inventors in 2005, whereas 35% of them were from chemistry, 19% from technological processes and 16,6% human necessity matters. With following four years the number of patent and utility model applications has increased (accordingly to 72 and 128 applications), but the importance in chemistry/metallurgy, technological processes and human necessity matters has decreased. In 2009 only 6,25% patent applications were related to chemistry/metallurgy, 6,25% with technological processes and 3,13% with human necessity matters. In utility model application numbers the situation was a little bit better only in technological processes and human necessity matters, where percentage from all utility models in both cases was 9,85%. Estonia has been successful in subcontracting and the need to develop its own products has remained on the background. Indeed, nowadays the partnership in EU has increased, financial interest of investors and labor cost have increased rapidly, but awareness of innovation is still relatively low compared to Western and Northern European countries. Therefore, it was researched whether this poor activity is connected with labor competences via online questionnaires, taking into account influence of technological capacity. According to research human's skills, knowledge, experience and motivation were wished to be applied in team influence innovation capacity. Using the same equipment and applying the same organizational methods, one could be more productive than another during the same time. Levels of skills and knowledge (competences) of performing tasks determine how well everyday tasks can be completed. As a result, an integrated virtual database was created for educational and industrial needs in the sector. The initial database for online monitoring of workforce competence was elaborated in EU projects Innomet and Innomet II by 7 countries – Estonia, Finland, Hungary, Italy, Latvia, Portugal and Sweden. It includes links to existing educational opportunities, e.g. different levels of study programs, as well as private sector qualified labor force and mapping of the industrial needs for human resources. A comprehensive research targeted to investigation of needed and existing competencies in different workshops was conducted in these countries. In Estonia data about employees' existing and necessary levels of competences were gathered and analyzed in case of 75 machine-building, metalworking and apparatus industry companies. In the elaborated model, the existing levels (EL) and needed levels (NL) were estimated in scale 0-5 where 0 means "the skill has no importance" and 5 means "the skill has high importance" [Riives, Otto, Keerman, 2007]. In case of EL<NL additional trainings were required. The requirements for the needed level should ideally comply with the existing knowledge and skills of the employee.

Thus, all enterprise competences (EL and NL) were mapped and training needs determined in the first stage of the process according to competency charts of the company. As an example, one part of the competence card from online questionnaire for miller is presented on the Figure 4.1.

All competency charts were filled personally for each vocation in the enterprise. The charts can be completed by enterprise online, with the sensitive information of the enterprise remaining undisclosed. For general professions special standard templates have been created, e.g. the results of queries concerning CAD designers in 18 Estonian enterprises are depicted on Figure 4.2. Competences were divided into four main groups: general, basic, special, and personal.



innomet

TÖÖKESKKOND (LIVE)

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Skill cards | Organizations | Reports | Classificators | Settings | Other | Logout

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Edit the required skill card values

Skillcard name **Miller**

Organization Clyde Bergemann Eesti AS

General skills

	skill	default
1	computer literacy	2
2	general knowledge about milling benches	4
3	knowledge about engineering technology	4
4	knowledge about work safety	4
5	general economic knowledge	3
6	language skills	3

Basic skills

	skill	default
1	ability to measure components to be measured	5
2	knowledge about and usage of measuring and inspection tools	5
3	knowledge and usage of cutting instruments	5
4	knowing technological possibilities of milling benches	5

Figure 4.1 Part of the competence card for the miller position

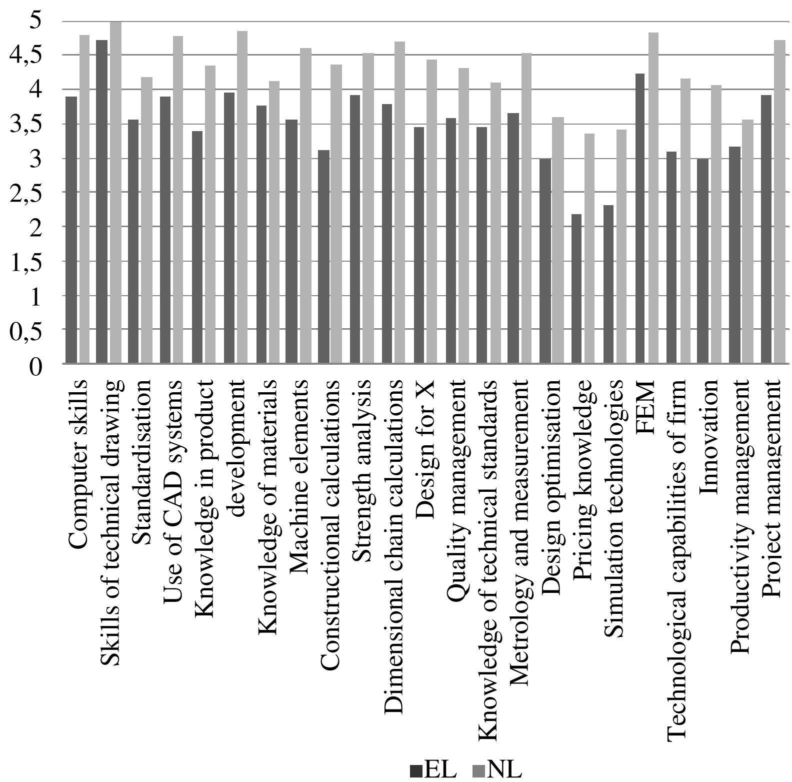

Figure 4.2 Existing (EL) and needed (NL) competences of CAD Engineer

The second stage includes arrangement of training courses according to the needs that were mapped. Thus, the input was obtained from an analysis of all Estonian educational organizations of the sector. The training activities were organized based on unified training calendar and the corresponding documentation. By the information of Figure 4.2 educational institutions could draw conclusions and offer corresponding training courses, e.g. a course of Innovation could be advantageous, at the same time a course of project management appears to have less potential. Before the system was implemented vocational training courses were organized independently by tailor-made course plans. The new monitoring system made it possible to support organizational work by adding value through different queries, statistical calculations and prediction mechanisms.

The regional analysis of companies is depicted on Figure 4.3.

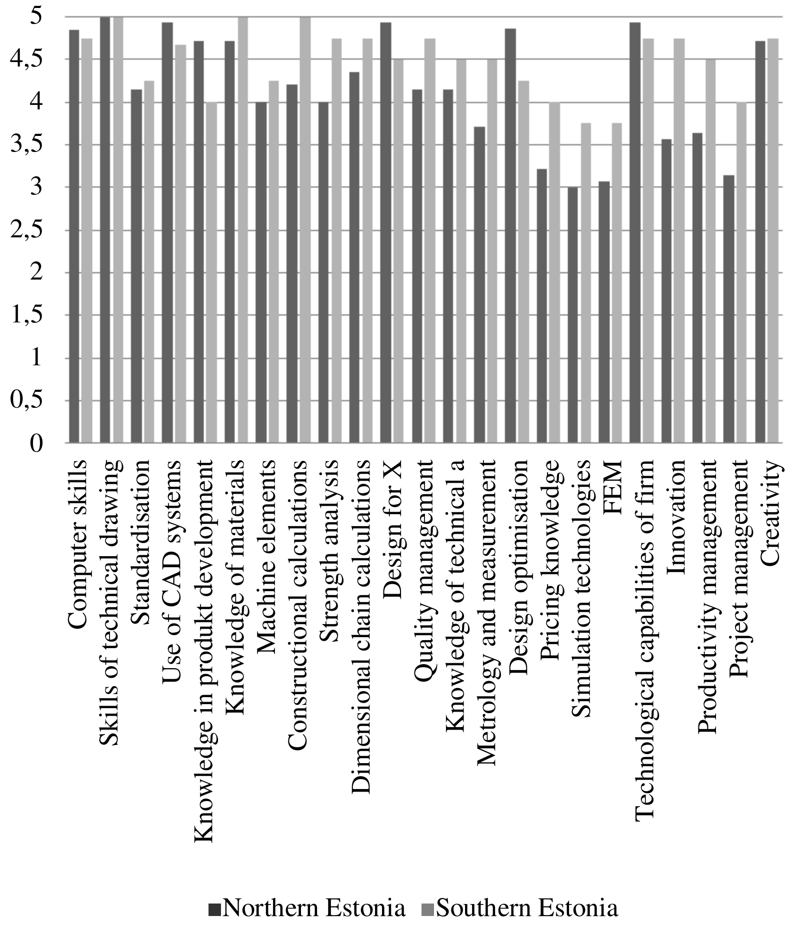

Figure 4.3 Differences in estimated existing level of competence between Northern and Southern Estonia

It is noticeable, that there were differences in estimated levels of competence between Northern and Southern Estonia for CAD Engineer profession. The overall pattern appeared similar for both; however Southern enterprises valued their competence more highly than Northern enterprises. Concerning CAD, Northern Estonia is more influenced by the Tallinn University of Technology, whereas Southern Estonia is more closely connected with the Estonian University of Life Sciences.

When the North was more confident with CAD systems, knowledge in product development, design for X and design optimization, the South estimated higher its knowledge of materials, constructional calculations, innovation and project management. As a result, in 2005/2006 several new vocational training courses were developed for industry, using the best lecturers from universities and the industrial sector (e.g. courses 'Product Development', 'Modern Technologies, Materials and Measurement Techniques'). It improved considerably an open dialogue between educational institutions, the private sector and other related organizations.

After all, in order to make the necessary level comparable, a web-based expert tool was developed. An online questionnaire concerning enterprise technological resources and engineering level with questions about the current profession was developed.

During competences estimation, it was important to separate high-tech related needs, because they grow faster than the overall economy. In addition, innovation indicators were included in an expert tool and used for staff selection for demanding research projects. The proposed indicators for an expert-tool were the following:

1. University degree of staff members;
2. Academic research and development funding;
3. The number of patents and utility models issued by company;
4. Scientists and engineers as a share of the workforce in the company;
5. The number of scientific publications during last 5 years of current staff member;
6. Creativity enhancing in the company;
7. Activities suitable in enterprise environment: meetings, negotiations, measurements, testings, electronics handheld works.

As for example, questions for product developer position are presented in Table 4.1.

Table 4.1 Expert tool rule base for product developer/CAD engineer

PRODUCT DEVELOPER				
Situation description				
1	Foreign languages skills			
		1-2	3-4	over 5
	Weight:	1-2	3-4	5
2	Average number of product development engineers in the enterprise			
		less than 5	5-15	over 15
	Weight:	1-2	3-4	5
3	Virtual testing			
		Virtual testing is not used	Virtual testing is used in some cases	Virtual testing is necessary in all developed products
	Weight:	1-2	3-4	5
4	Annual R&D budget share of company (million EUR)			
		Less than 0,2	0,2-1	Over 1
	Weight:	1-2	3-4	5
5	IP politics in company			
		Patent search is not necessary in product development	Patent searches are necessary	There is IP specialist in the company for patent search
	Weight:	1-2	3-4	5
6	Market analysis for product done in product development			
		Regional analysis	European level analysis	Global level analysis
	Weight:	1-2	3-4	5
7	Prototyping			
		Prototypes are not built	Simple prototypes	Full scale complex prototypes
	Weight:	1-2	3-4	5
8	CAD system used in company			
		2D	3D	FEM
	Weight:	1-2	3-4	5

To achieve higher innovation capacity it is suggested to evaluate professional competence (e.g. see Table 4.1) and thereafter select team candidates so that a condition

$$\text{NL (profession)} = \text{EL (innovation skill)} \qquad (4.1)$$

is satisfied. The relation (4.1) is effective when NL (needed level of profession) and EL (estimated level of innovation skill) are integers.

4.2 Expert Tool Implementation – a Case Study

In chapter 3.1 a case study about RFID reader housing development was described. The same part development process was used also for trying to implement this expert tool for the first time.

The prototype solution was targeted to small and medium enterprises (SME-s) oriented to low volume production requiring enterprise cooperation e.g. machine industry and the university. The target was to develop the housing that is modularized and compact. As there was the need for cooling the device, the collaborative engineering merging competences of different fields of industry were unavoidable. For that reason CE was involved in NPD and RP process. Product developers were selected from the following areas: from electronics, mechanical design and thermal engineering. The competence level for general product developer according to the previously introduced expert tool evaluation was pointed out as high as 4.4.

The relation (4.1) is effective only when NL and EL are integers. Therefore, people participating in the project team should have innovation skills over 4 whereas total innovation skill of the team best result was 4.4. In practice it meant the following requirements for project team members: university degree MSc or PhD; number of scientific publications during the last 5 years over 10; existing special facilities for project meeting; available environments for measuring, testing and electronics work provided by university. The requirements of R&D funding, number of patents and share of scientist in the university were satisfied on high level. The development of the new device was used as a basis for identifying innovation indicators. The proposed developed expert tool is available at http://innomet.ttu.ee:8080/innomet/. It is based on MySQL and Apache Tomcat freeware environments and is easily adjustable.

The case study confirmed that evaluated team-members selection taking into account innovation skill (EL) from the developed expert tool, enabled resulting and effective NPD process that was described in more detail in chapter 3.1.

4.3 Conclusions of the Chapter

The influence of innovation to productivity has been so far investigated mainly from the viewpoint of economical science. But it was discovered that innovation capacity could be viewed also from the enterprise employee's competences point of view. Therefore, in current study innovation and its capacity was handled from employees competences point of view in more detail.

The existing and necessary level competences of Estonian engineering industry enterprise employees were mapped. Taylor-made trainings for competence improvement in cooperation with Estonian universities and vocational education centers were proposed. In order to make existing level competencies comparable, an expert system was developed including innovation indicator that helps to select suitable team-members into more innovative product development team. Therefore, innovation capacity as a part of company/university infrastructural characteristics was important to develop. As a result, models suitable for monitoring innovation capacity for SME-s were elaborated that enabled to understand the enterprise competence levels by professions.

1. The proposed solution is capable of monitoring the quality and quantity of employees' competences in machine-building enterprises of the network.
2. The influence of human resources can be evaluated successfully, when using proper taxonomy and expert estimations. The results were positive and the elaborated expert tool has demonstrated the ability to enable competence development.
3. In case of high-tech research, better results can be achieved, when a team is selected according to expert evaluation of necessary competences. A case study showed that in practice pre-estimation of team workers by taking into account completed competence covering weak areas was successful. Comparing the necessary level for profession and existing level of innovation skills when creating a project team enhances innovation productivity.

5 NEW APPROACHES IN DATA MANAGEMENT

Nowadays there is a huge amount of data in all fields of life. Each field finds their own methods and success stories. Therefore data is analyzed and implemented for further product or service improvements. In the current chapter data management possibilities in manufacturing and e-solutions area are described in more detail.

During the enterprise employee's competences mapping, data about Estonian engineering industry enterprise competences were collected. It gave the excellent possibility to think about future developments regarding online resource databases that could enable effective cooperation of production enterprises at least in engineering industry sector. Therefore, information for better cooperation between engineering industry enterprises was collected and elaborated on data structure presented in the current chapter. In order to manage this huge amount of data, there was the need to find out the suitable method for it. Therefore, the data mining method is analyzed based on concrete example by investigating data mining program "Clementine" possibilities.

Secondly, data management possibilities were examined in more detail for e-solutions and e-manufacturing. The solutions for achieving better results in customer service by taking into account data mining will be proposed. Therefore, the conception for managing RP ordering service from the Tallinn University of Technology to Estonian SME-s will be proposed and handled in more detail.

5.1 Data Mining Implementation in Production Management and Manufacturing

Importance of data collecting and storing is growing also in engineering sectors. Traditionally, analysts have performed the task of extracting useful information from recorded data. But the increasing volume of data in modern business and science calls for computer-based approaches. As data sets have grown in size and complexity, there has been an unavoidable shift away from direct hands-on data analysis toward indirect, automatic data analysis using more complex and sophisticated tools. Nowadays the modern technology has made data collection an almost effortless task. However, the captured data needs to be converted into information and knowledge to become useful. It was mentioned above that data mining is one of the computer-based methodologies that includes new techniques for knowledge discovery from data [Kantardzic, 2003] Therefore, this method has generated wide interest.

During the past few years data mining has been widely used only by companies with a strong consumer focus like retail, financial, communication, and marketing organizations and enabled to determine relationships among "internal" factors such as price, product positioning, and "external" factors, such as economic indicators and customer demographics. It has been used primarily in financing sector. Novel applications to inventory management and an inventory classification problem using data mining and seriation has demonstrated great potential also for engineering industry [Liiv, 2008]. In fact, the knowledge discovery activity could become the key factor to innovation and business success [Kusiak & Smith, 2007].

Conventional databases have been developed to integrated systems, but due to the increasing amount of data feeds about enterprise general information, it's employees' skills and technological capabilities, led us to the understanding, that a novel analysis method was to be applied. Therefore, DM method was researched in more detail for analyzing data gathered about Estonian engineering industry enterprises. Thus, data mining implementation possibility in production management and manufacturing is one of the key questions of the current chapter. In the current chapter data mining (DM) implementation will be viewed from the DM main principles point of view that was introduced in chapter 1.4. Taking into account these principles, the whole Data Mining Process (DMP) was investigated based on an example in manufacturing area for understanding what should be followed for the method implementation.

Firstly, in order to implement the DMP to the production management and manufacturing sector, it is important to understand the business problem – what is our aim with the gathered data and what does the data concern.. It is obvious that all data need to be in an easily accessible format and available from one central database. It is often the case that relevant data files are stored in several locations and in different formats and need to be collected before analyses. The extracted information and knowledge can assist the engineers as their reference and basis for advanced investigation of the root causes of the defects [Larose, 2005]. In the current research data is used about enterprises, their technological capabilities, and employees' competences from three different databases: Metnet, Innomet and Innoclus. Data were gathered for online resource database that could allow effective cooperation of production enterprises in engineering industry sector. For data analyzing the data understanding and preparation are unavoidable phases in DMP. Also there is a need to assess the data for the data mining project. Therefore, aspects, which have to be clearly considered, are the following:

Relevant factors covered by data

For making a data mining project worthwhile data must contain all relevant factors/variables and be mutually adjustable. Therefore, data were separated into different tables according to logical themes. For example, one table includes all information about enterprises contacts, other enterprises technological capabilities, etc. It is smart to hold the data in different tables, because it simplifies the data understanding and facilitates later the DMP. In order to join data between these thematically separated tables, the common ID-s (enterprise_id, sector_id etc) were elaborated. As in our case, data came from three different databases (see Figure 5.1): enterprises information from Metnet, technological capabilities from Innoclus and enterprise employee competences from Innomet, there existed the need to work out common data structure together with thematically separated data tables with common attributes. Data that came from three primary sources (Metnet, Innomet and Innoclus) was joined in main database based on common ID-s.

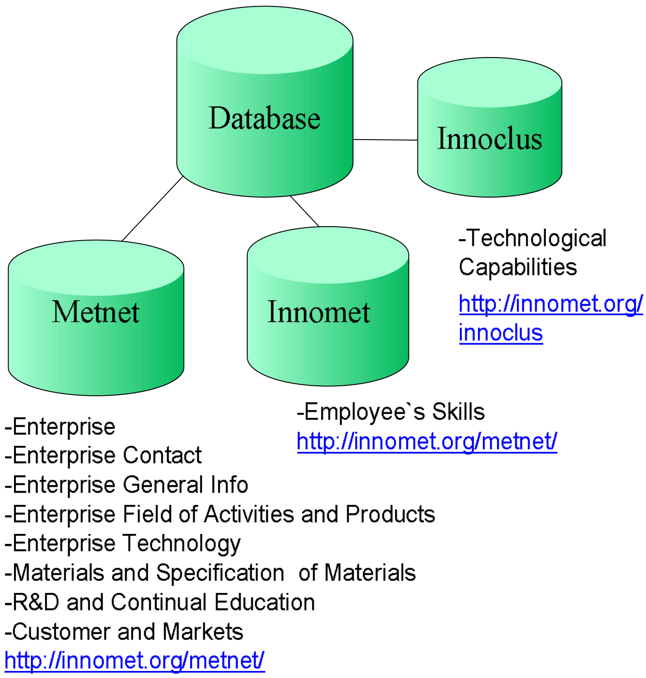

Figure 5.1 Common database backgrounds

The whole data structure elaborated for joining data from different sources is presented on Figure 5.2. In addition, this data model illustrates, which common ID-s have been worked out in order to join the data from thematically separated tables. Description for data model table values is presented in the appendix.

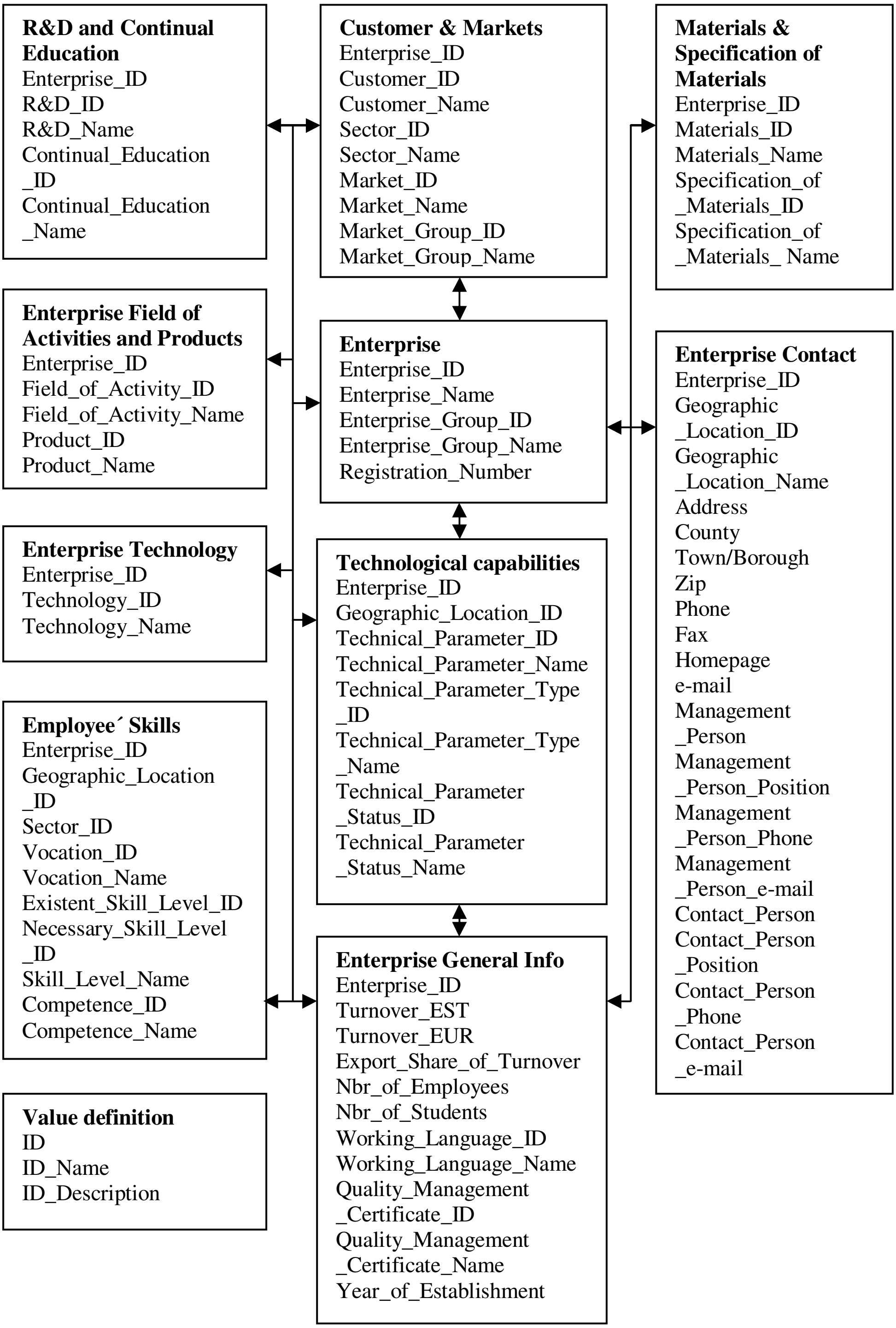

Figure 5.2 Conception of data model

Handling noisy data

The term „noisy” in data mining refers usually to errors in data or also sometimes to missing data [Hastie, Tibshirani, Friedman, 2001]. In the current study we had to handle the problem, as well. It results from the data collection. All data about the enterprises capabilities were gathered without multiple-choices. Initially the question options were not defined and therefore every enterprise answered to the questions differently. In order to understand the answers unambiguously, it was clear that the data synchronization for effective data management is unavoidable. The solution for employee’s skills/competences and enterprise technological capabilities could be simpler, as the multiple-choices have been worked out and enterprises have answered the questions by conducting suitable selections.

Gathering sufficient data

It is obvious that the more complex patterns and relationships we wish to find, the more records are required. There is a self-evident difference, when we analyze ten, one hundred or all Estonian engineering industry enterprises. It is important to point out, that in our case study all engineering industry enterprises have been included and that information has been gathered and therefore can be used in different analyses by using data mining method.

The next step, after the data structure has been created and “noisy data” eliminated, it is possible to continue with data management in more detail. When the data is gathered into one central database and is logically structured and therefore easily understandable, DM can offer many different applications. We can build models able to predict different important indications for better and more effective production management. For example, it may be possible to create the predictive data mining model for investigating competences necessary for most effective product development. In addition, it may be possible to classify enterprises for different clusters based on different technological capabilities. Therefore, the data mining implementation can be also effective in manufacturing sector and certainly necessary for improving enterprises productivity and innovation in product development and manufacturing.

As the central database has not been established yet, data mining models developing cannot be investigated further and thus is introduced only on concept stage. But for better understanding of data preparation matter and the essence of common data structure creation, the example of DM implementation possibility is described in more detail. It helps to understand previously described data structure necessity and presents, how by using DM program “Clementine” it is possible to search necessary information from large database in a few minutes. The aim of example is to find from all Estonian engineering industry enterprises the enterprise, the technological skills of which in mechanical treatment of steel and aluminum products are on the highest level. The enterprise has to be located in North-Estonia. Thus, the aim is known for DM and the next step encompasses data understanding, where main criteria listings are helpful for building the data mining stream. In that case, the main criteria that should be taken into account are as follows:

- Enterprises are located in North-Estonia.
- Enterprises deal with mechanical treatment of steel and aluminum products.
- Employees` technological skills are on the highest level.

It means that by taking into account previously listed criteria, it is simpler to create a query (in other words build up the stream) for finding the result. On Figure 5.3 the target solution is depicted.

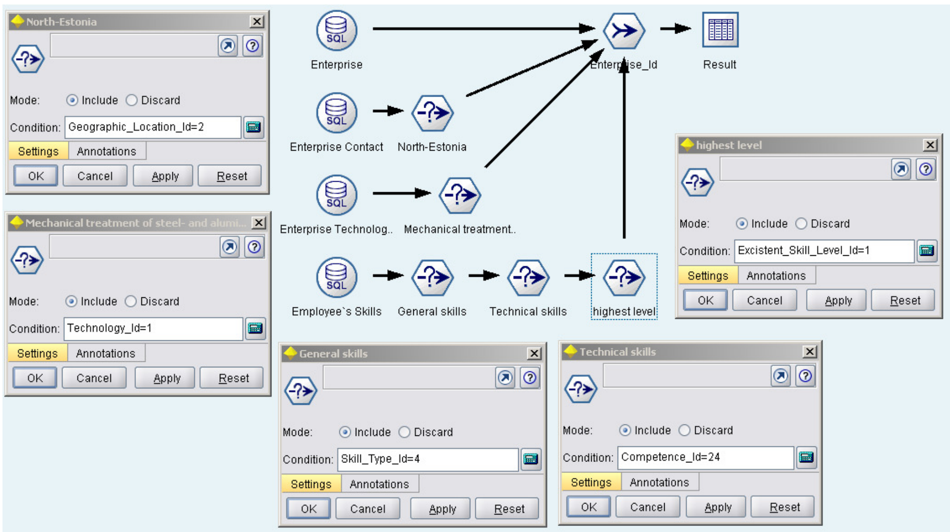

Figure 5.3 Clementine stream

The DM stream built for searching the enterprise to satisfy previously listed criteria is presented in the center. Data mining stream was built up by taking into account knowledge about previously described database structure. The aim of DM stream is to use necessary selections for reaching the correct result. In current case the stream should find the enterprise, which is located in North-Estonia and has the highest level competences in mechanical treatment of steel and aluminum products. Therefore, the selection conditions necessary for stream building are pointed out around the stream. All conditions together create the sequence of commands. On the other hand, they create a data mining stream that leads to the searching result. Next, each selection condition (command) from the stream with detailed descriptions is pointed out.

Geographic_Location_Id=2

As the enterprise locations were described in the database as follows:

Geographic_Location_Id=1, when Geographic_Location_Name= West-Estonia

Geographic_Location_Id=2, when Geographic_Location_Name= North-Estonia
Geographic_Location_Id=3, when Geographic_Location_Name= Central-Estonia
Geographic_Location_Id=4, when Geographic_Location_Name= South-Estonia
Geographic_Location_Id=5, when Geographic_Location_Name= East-Estonia
the selection for picking up the North-Estonian enterprises was defined by using Geographic_Location_Id, which in the case of North-Estonia was 2.

Technology_Id=1
Every technological capability was defined separately in the database and marked with specific ID. Since the technological capability - mechanical treatment of steel- and aluminum products has been defined in the database with the technology ID 1 the selection condition was that kind. All Technology_Id definitions are not presented here, because there were more than one hundred technologies.

Skill_Type_Id=4
Similarly to prior reasons, the selection has been done according to the data definition in database.
Skill_Type_Id=1, when Skill_Type_Name= professionalisms
Skill_Type_Id=2, when Skill_Type_Name= personal identities
Skill_Type_Id=3, when Skill_Type_Name= base skills
Skill_Type_Id=4, when Skill_Type_Name= general skills

In order to accelerate the query, it was necessary to use information about skill's type. As it was known, that the competences were divided into four main groups, it was smart to decrease the query volume and search the highest level competence only from the group where it belonged.

As the skills were divided into four main groups: general skills, base skills, professionalisms and personal identities and technical skills were one part of the general skills, the necessary selections were made by using the following selection commands: General skills->Technical skills->Highest level. That kind of selection helped to speed up the query, because the technical skill was required only among the general skills and search from other skill types were excluded.

Competence_Id=24
The selection condition was done again according to the database data definitions, where every skill was defined separately and marked with its own specific ID. Technical skill was defined in the database with Competence_Id=24.

Existent_Skill_Level_Id=1
Skill levels were defined in the database as follows:
Existent_Skill_Level_Id=1, when Skill_Level_Name= the highest

Existent_Skill_Level_Id=2, when Skill_Level_Name= high
Existent_Skill_Level_Id=3, when Skill_Level_Name= medium
Existent_Skill_Level_Id=4, when Skill_Level_Name= low
Existent_Skill_Level_Id=5, when Skill_Level_Name= the lowest

Therefore, making correct selection conditions for the stream, it is possible to merge necessary data based on common ID-s and significantly accelerate the query. After the stream has been completed, necessary selection conditions were described and all commands joined with each other, the stream was executable. As a result of the query the searched enterprise(s) should be listed in the table.

To sum up the chapter, it was discovered, that data mining is widely used in financial and commerce field, it can also be implemented for giving important findings from enormous data amounts in engineering sector. Integrating a data mining framework within the manufacturing information system enables to improve manufacturing decision-making process and enhance the productivity. It enables to analyze enterprises opportunities and employees' skills and competences, find relations between enterprises, customers and subcontractors, and make consequences based on different data conjunctions.

From the online resource database point of view, it can allow effective cooperation of production enterprises at least in the machinery sector. Adding search engines that are able to propose a full production chain implementing user needs and restrictions can significantly increase usability of such databases. The system therefore can support the strategic planning of technology transfer and can be used as a basis for the industrial enterprises in elaborating co-operation networks and developing towards extended enterprises.

5.2 Data Management in E-Solutions and E-Manufacturing

E-solutions have offered new opportunities for large and small organizations to compete in the global market. For manufacturing companies the most valuable term is e-commerce referring to e-business and e-manufacturing, as well. These both can be conducted over the Internet and can be available for clients in any time in any place, where the Internet connection is available.

Today, many business transactions occur across the telecommunications network where buyers, sellers and others involved in the business transaction rarely see or know each other and may be located anywhere in the world. This process of buying and selling of products and services across a telecommunications network is often called electronic commerce or e-commerce. Most people today use the terms e-commerce in its broadest sense and e-business interchangeably. Others refer to this broader spectrum of business activities that can be conducted over the Internet as e-business [Napier, Rivers, Wagner, 2005]. Therefore, major corporations often reorganize their businesses in terms of the Internet and its new culture and capabilities.

In addition, electronic customer relationship management plays an especially important role in company's customer service process. The conduct of business using Internet technologies continues to be a significant, pervasive issue for both: enterprises and customers [Fjermestad, Romano, 2008]. Like all others, manufacturing companies also can use the Web as a competitive advantage not only for e-business, but in addition for e-manufacturing and other innovative solutions like digital factoring or e-laboratory.

Today the accessibility of market and responsiveness are the main core for success. Therefore, new possibilities for selling company developed products and services are the main key factors. And e-business seems to be one opportunity for it. It is already known, that e-business derived from such terms as "e-mail" and "e-commerce," is the conduct of business on the Internet, not only buying and selling but also servicing customers and collaborating with business partners [Hand, Mannila, Smyth, 2001]. The benefit for company is cost and time savings from customer services. Estimation functionality has given the customers the possibility to test alternative variants in order to investigate the most suitable manufacturing path for the desirable product or service.

Therefore, in the current chapter e-commerce solutions have been handled in more detail. A solution for providing more effective cooperation with clients is proposed taking into account the DM implementation possibility. The proposed developed solution for more innovative e-manufacturing describes how it is possible to improve the e-service. Thus, in that chapter, KPIs for innovation and NPD have been handled mainly from the customer service improving point of view that new e-solutions could help to achieve.

5.2.1 E-Solution for Rapid Prototype Manufacturing

Online analysis and cost calculation solution proposed for ordering manufacturability parts from the Tallinn University of Technology (TUT) via Internet are presented below. The core of an e-solution strategy is information sharing between the customer, manufacturing operations and suppliers. The concept of solution is: servicer (e-solution provider) finds new customers providing the quick and easy RP manufacturing solution to the clients and from another side client (service user) receives a quick overview about the cost and time of manufacturable part. This solution should help service orderer to decide, weather the RP manufacturing service is acceptable or not.

As owning RP devices are expensive for ordinary Estonian SME-s, the Tallinn University of Technology (TUT) and enterprises have to co-operate regarding product prototyping. The Tallinn University of Technology has a long experience with prototyping in Estonia, because the first 3D printer in Estonia came into use in TUT. Therefore, the university is interested of prototyping not only inside the house regarding studies but also would like to provide this opportunity outside the university. Therefore, e-manufacturing solution for prototyping service offering seemed to be a good opportunity for extending cooperation between university and enterprises. Thus, the e-solution for rapid prototype manufacturing was analyzed and proposed. Cost estimation rules have been analyzed based on casing of an autonomous robot device case study taking into account amortization of the machine and several preparations and finishing steps of prototyping in case of PLST technology. As there was also a problem with prototyping and e-manufacturing time estimation for PLST technology, data mining implementation was considered.

5.2.1.1 Cost and Time Estimations

The matter derives from the development and manufacturing a casing of an autonomous robot device. The device had to resist slight impacts and humidity. The weight is definitely important, as the decrease of the weight reduces the impact on falling and energy consumption when in the motion. Thus, 3D-model of the prototype was created by using PLST technology with Formiga P100 (overall sizes of building chamber 200 x 250 x 330 mm). The desired casing consists of two similar sides (Figure 5.4) and has several elements for fixing different modules of the device. Hence, the geometry is relatively complicated. For finding manufacturing path alternative technologies as milling, vacuum forming, PLST, etc., were analyzed. PLST, compared with the other technologies, provides the probability to obtain the desired casing with no restrictions. The manufacturing technology was easily applicable and most of the models manufactured without any modifications.

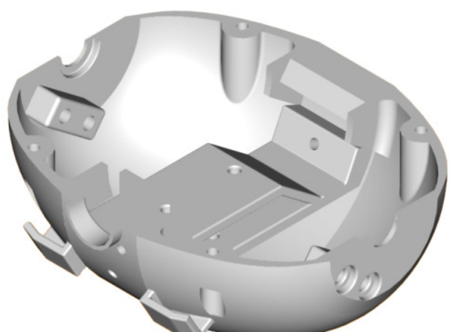

Figure 5.4 First side of the casing.
Dimensions 105 x 89 x 46 mm. Volume 55 770 mm^3

In case of SLS technology, RP is based on slicing a three-dimensional model and producing a part layer by layer using that information. SLS is one of the RP technologies that produce parts by adding material by layers. If comparing it with another RP technology - three dimensional printing enables to manufacture not only fragile design models, but also products capable for individual and small series. In the sintering-process that is presented on Figure 5.5, the plastic powder is heated with a laser beam over its melting point and as the material cools down solidified layer is formed. The unsintered material has the supportive function. As the parts cannot be sintered directly to the build platform, a powder bed is needed. In addition several layers of material are spread onto the produced parts. Both, the powderbed and top-layers, carry the function to smoothen the cooling process after manufacturing. The first expenditure if manufacturing parts by SLS is the plastic powder. The material is directly used to the manufactured parts, but as the process chamber is heated near to the material melting point, the rest of the supporting material is also affected and as it has to be „refreshed" with new powder, additional powder is spent. Depending on the machine, SLS-machine tools mostly consume electricity and compressed air, hence these costs and in addition the amortization of the machine need to be taken into account.

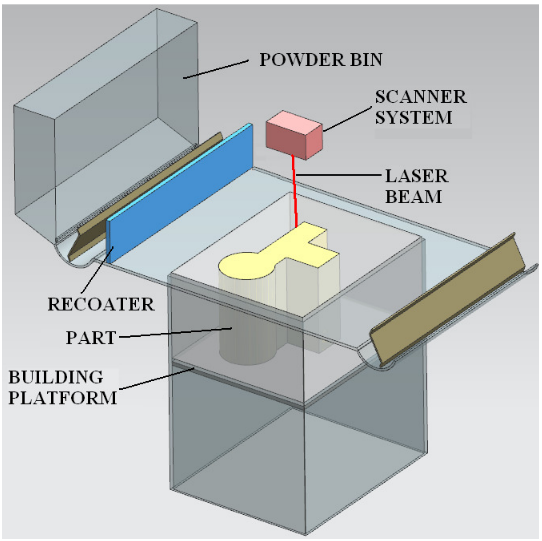

Figure 5.5 Laser sintering process

Depending on the machine, Formiga P100-machine tools mostly consume electricity and compressed air. Hence, these costs and in addition the amortization of the machine had to be considered. As the building process required several preparation and finishing steps (preheating of the process and building chambers; spreading the lower and upper material layers), that were executed always when performing the task, it was possible to handle these expenditures (Eq. 5.2) separately from actual building costs (Eq. 5). Summing up the preparative and finishing steps with actual PLST building total cost was calculated with equation 5.1. The components of preparative and finishing costs derived from equations 5.3 and 5.4.

$$C_T = C_{pf} + C_{build} \quad (5.1)$$

$$C_{pf} = C_{mat.-pf} + C_{electr.} + C_{comp.air} + A_{pf} \quad (5.2)$$

$$C_{mat.-pf} = V_{layers} * \rho_{powder} * C_{w-unit} \quad (5.3)$$

$$A_{pf} = \left(t_{heat} + t_{lower+} t_{upper}\right) * C_{t-unit} \quad (5.4)$$

$$C_{build} = C_{mat.-build} + A_{build} + C_{electr.} + C_{comp.air} \quad (5.5)$$

$$A_{build} = l * t_{layer} * C_{t-unit} \quad (5.6)$$

where:

A_{pf} - amortization of machine for preparative and finishing steps;
A_{build} - amortization of building part;
C_{build} - part(-s) building costs;
$C_{comp.\ air}$ - cost of compressed air;
$C_{electr.}$ - cost of electricity;
$C_{mat.\text{-}build}$ - material costs in building step;
$C_{mat.\text{-}pf}$ - material costs in preparative and finishing steps;
C_{pf} - preparative and finishing costs;
C_T - total costs of the part manufactured with SLS;
$C_{t\text{-}unit}$ - cost per time-unit;
$C_{w\text{-}unit}$ - cost per unit of weight;
l - height of the part;
t_{heat} - heating time;
t_{layer} - layer building time;
t_{lower} - time to spread the lower material layer;
t_{upper} - time to spread the upper material layer;
V_{layers} - lower and upper material-layer volume;
ρ_{powder} - density of powder.

It was already mentioned that the parts are made layer by layer. If the volume of the part, layer thickness in use and approximate layer building time are known, then it is possible to calculate approximate part costs to each part using their height. In Eqs. 5.5 and 5.6 are described the components of costs that result from actual building of part(-s). Although the layer sintering time depends from the amount of the material to be sintered on actual cross-section, the quantity of layers has the main affect to the time altogether. In Eq. 5.6 is described the components of costs that result from actual building of part(-s).

Although the layer sintering time depended on the amount of the material, the quantity of layers chiefly affects the time. Combined with data mining using these formulas, it was possible to create manufacturing cost and time estimators, which can be made available to customers in an online service. Achieved estimated results have been in correlation with post-audit results.

For manufacturing time estimation research, SLS-machine EOS Formiga P100 was used. The layer thickness in use was 0.1 mm and as the height of the higher part was 52 mm, thus 520 layers were spread to build the parts. The layer building time was taken in the estimation on the average 30 seconds. Hence the estimated time to build the two sided casing is 4.3 hours, but the preparative and finishing steps prolong the actual time. In addition, the part has to cool down, which takes approximately the same time as for the building. To sum it up, the casing type parts presented on Figure 5.4, can be manufactured from electronic data model to physical prototype in above mentioned conditions in 13 hours.

5.2.1.2 Data Mining Implementation for E-Manufacturing

Previously it was introduced, how the calculations should be made for rapid prototyping manufacturing with PLST. Now it can be observed, how these calculations together with service ordering can be available for customers via online service. Therefore, the whole online based analysis and cost estimation solution for RP manufacturing with PLST technology will be described in more detail.

The main aim is to give the service orderer the opportunity to analyze manufacturable part cost and production time before sending the job to TUT. It gives to the customers the advantage to make modifications to the manufacturable parts and see how it affects the service price by just changing the model. As by growing amounts of inquiries the usable data gained from prototyping estimator probably increases, data mining analysis could give important findings for service provider from its improvements point of view. Therefore, in the following chapter, the conception of RP manufacturing service ordering via e-solution (e-manufacturing) will be handled and the solutions regarding DM implementation proposed. Firstly, it could be possible to analyze service orderer's data and decide what kind of enterprises use the service and which use online service only for cost estimation and then abandon from the service ordering. Therefore, such predictive models can be created, if in addition to manufacturability part information also data about enterprise general information is collected. It can be possible to create predictive DM models for finding interesting patterns from collected data, e.g. whether the online service is popular among small and medium sized enterprises or big companies; what is the number of development employees, the company's turnover etc.

The e-manufacturing platform is in elaboration stage, a new competence centre IMECC has been established connecting IT and engineering companies but also the Tallinn University of Technology to achieve this target. Therefore, since the e-solution is on the concept stage and is not physically implemented, the data mining implementation for e-manufacturing can be handled only as an idea for achieving better results in service providing. All the same, the general conception of DM implementation into online service system is presented on Figure 5.6.

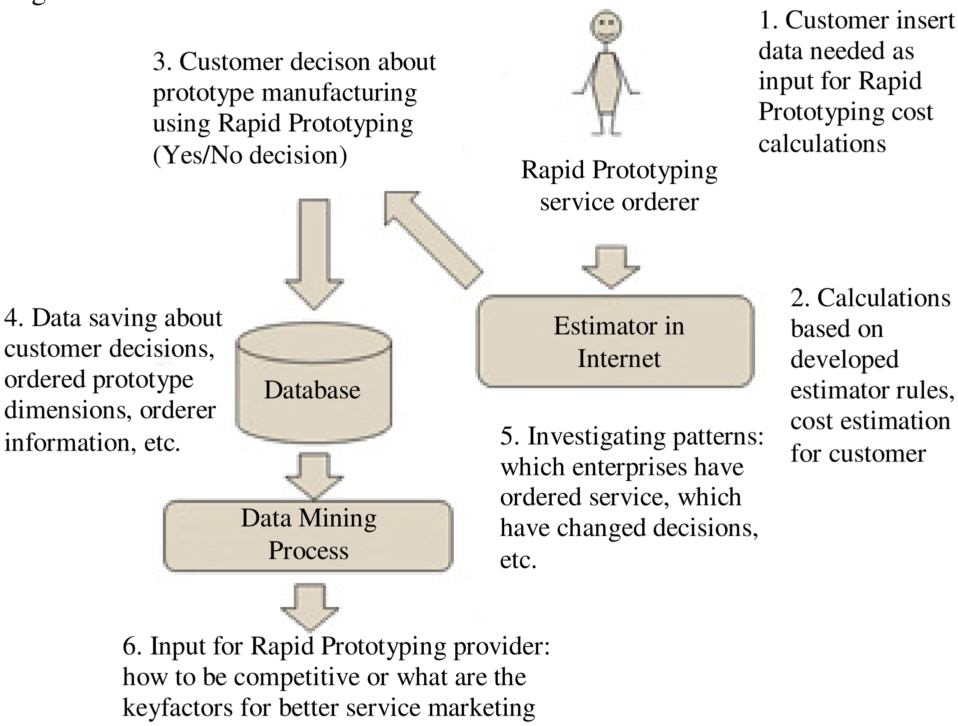

Figure 5.6 DM implementation for RP service ordering/e-manufacturing

The main aim of the e-solution is to enable customers to order rapid prototyping manufacturing service from the Tallinn University of Technology electronically. The idea is to give Estonian small and medium sized companies the possibility to order prototyping service based on 3D printing technology (PLST) via Internet. In order to provide most convenient and fast service on the market, the service ordering process should consist of e-technologies like available cost estimator and online booking-consultation tool via Internet. The service ordering process consists of different steps and assumes from service provider not only cost estimator and online-booking system creation, but also database development. It is necessary for understanding the customer behavior that is important for strategic decision making regarding e-solution providing improvements.

Briefly, the whole conception of provided e-solution is the following. The main competence advantage is the cost estimator that enables customers to calculate/estimate RP cost based on manufacturability product dimensions and volume. Secondly, another part of the concept is to save all orderers' data about the prototype dimensions and also information about companies to the database for the following reasons:

- To understand the real manufacturing time. With DMP it is possible to investigate more realistic RP manufacturing time, based on already collected different RP manufacturing times. Initially the cost estimation together with RP manufacturing time to the customer can be rather vague. Therefore, with DM analysis it can be possible to predict more accurate RP manufacturing time for the service orderer.
- To investigate customer's feedback and analyze which companies order the service most often and which use online based RP cost estimator only for their interest of service cost. Based on the saved data with DMP it will be possible to find out customers who have been interested in service but have not ordered it. Therefore, it is possible to make some future marketing decisions or furthermore, RP service cost can be reviewed in order to win the competence advantage on the market.

Main conclusions:

1. Integrating a DM framework within the manufacturing information system enables to improve manufacturing decision making process and enhance the productivity. It enables to analyze enterprises opportunities and employee's skills and competences, find relations between enterprises, customers and subcontractors, and make consequences based on different data conjunctions.
2. The described toolset integrating RP cost model into e-manufacturing system and investigating the service usability by companies opens new horizons in manufacturing. DM is a promising method to handle the information and increasing the collaboration network.
3. Understanding the customer's behavior gives the possibilities to understand product/service failures and leads to deficiencies made up in engineering sector. Therefore, knowing and understanding data can add surplus value for enterprises to build new goals and operate in a more commercial way.

It can be pointed out that KPI can be viewed also from service quality point of view. The main findings that can be made for quality improvements can be achieved in machinery sector by co-operating between production enterprises, where online based databases offer an important role for sharing competences and technological resources between enterprises. On the other hand, e-services via online application like proposed solution for RP manufacturing cost estimation gives the possibility to be more available for the clients any time anywhere. Better results in servicing can be achieved by implementing DM method in learning customer behavior reasons. Thus, data analysis results can lead enterprises to make necessary changes in business strategy and help to achieve even better competence advantages.

6 CASE STUDY – KEY PERFORMANCE CRITERIA IMPLEMENTATION FOR INNOVATION AND NEW PRODUCT DEVELOPMENT

Running new product development effectively requires good decisions and it is not important to monitor only profitability and cash flow. Additional key drivers of innovation have to be found, that enable to achieve more effective results of product development. Additional factors that can be handled as additional key performance criteria in innovation and new product development have been investigated in the current study. Therefore, this chapter presents, how solutions that have been developed in the current research can help to improve development teams and SME´s to achieve better results in product development processes and be more innovative in idea generation phases. As an example, proposed solutions (methods for preventing rapid prototyping bottlenecks, enterprise employee competences assessment; expert system) have been implemented in case study regarding team selection for product family of souvenirs, conference giveaways or tokens productions.

Several competitions have been organized to find ideas for producing new souvenirs or giveaways for various events. A good example is a competition for finding new souvenirs for Tallinn in 2005. The main aim was to find souvenirs that contribute to international demonstration of our capital city – Tallinn. It was expected that souvenir for the competition emphasizes the originality and uniqueness of Tallinn, is interesting, eye-catching, aesthetic, and its production is feasible. The organizers received 112 ideas and chose 20 that emphasized Tallinn's originality and uniqueness, were related to Tallinn legends, stories or history and were attractive, high quality and aesthetically packaged and equipped with a personalized label. Feasibility of production was also considered. Similar competitions can be organized regarding conferences giveaways, university tokens or souvenirs for different purposes.

In order to be successful in competitions, it is important to differentiate from others with original ideas and be innovative not only with product design but also with its producing possibilities and production materials. Mostly artists and designers participate in these competitions. They have a lot of experience and necessary long-term skills in order to propose good ideas, but quite often they go into detail regarding product manufacturing and thus do not achieve good product quality. Thus, the proposed idea is not competitive. Often these ideas stay on idea level and unfortunately are not put into practice. In order to be more effective with idea generation and solution proposing for such competitions, it is suggested to approach to the product development by taking into account developed methods from the current research.

We propose that it is very important to generate ideas not only among artists and designers, but also include mechanical and material engineers in the team of product development. How to create a team with good benefits for innovation capacity creation is an important key driver of more effective business. We found that team composed not only of designers and artists but also other area specialists of mechanical and material engineering could enhance more productive results than product designers separately. Participation of engineers in idea generation phase simultaneously supports artists and designers with production possibilities and new technologies implementation opportunities. In such concurrent engineering approach idea generation is significantly comprehensive and realistic at the same time. The only question is: how to create an innovative team?

Therefore, it is very important to be able to evaluate and analyze enterprise employee competences for understanding, which personal and professional skills need to be improved for worker efficiency growth. In the current research employee competence cards for engineering industry enterprises vocations have been developed. Hence the assumptions for evaluating mechanical and material engineer competences on existing and necessary level have been guaranteed. In addition, developed web-based expert system helps to get an estimation of needed level for each profession in scale of 1 to 5 points. On the other hand, this expert system enables to assess product development team innovation skill also in scale of 1 to 5. After the necessary competence level for each product development team-member is generated by expert system according to team-member profession, it is possible to compare it with the whole team innovation skill level. The idea is that the innovation capacity inside the team is supported by all team-members. It is guaranteed, if expert system evaluation regarding team-member estimated competence level is integer with whole team innovation skill level (see formula 4.1). Therefore, it is important to use proposed expert system for evaluating the following professions needed levels: product developer, materials engineer, mechanical engineer.

Thereafter it is necessary to assess innovation skills of the product development team based on proposed indicators that have been presented in chapter 4.1. Finally, in order to ensure the development team competence advantage not only in idea generation but also in its realization, it is necessary that in relation 4.1. NL (each team-member profession needed level) is integer with EL (whole team estimated innovation skill level). Estimations are higher in five point scales, thus the most innovative should be the team that is composed for most innovative idea generation together with new technological possibilities implementations for its realization.

Therefore based on current research, it can be pointed out, that this web-based expert system for innovation capacity estimation promised to be a smart tool for putting together more innovative product development team and is an important key-driver in business. It should be taken into account as additional key performance criteria in innovation and new product development processes.

On the other hand, when the product development team is compiled and a good idea is selected from all generated ideas, it is necessary to prototype it in order to get an overview about the final product concept. In order to avoid the mistakes that have been done in earlier rapid prototyping processes, it is important to have an overview of rapid prototyping "bottlenecks" prevention possibilities that have been investigated in the first part of the current study. Main findings regarding rapid prototyping process improvement possibilities gives the development team the possibility to make the entire product development process more efficient because the need to change product constantly is avoided and therefore it is possible to reach the desired prototyping solution quickly.

Firstly, modularization and concurrent engineering implementation already in RP phase enable easily make changes in failure parts in product assembly. In addition, it owns positive effects for more effective collaboration already at the beginning of the product development processes – in product concept, RP and testing phases. Modularization implementation into concurrent engineering conceptual model enables to do parallel activities simultaneously due to modular parts of prototyped products. On the other hand, "bottlenecks" that have occurred earlier in RP practice can be prevented by the team in their RP process. It means that based on proposed method for estimating the uncertainty of arithmetic mean of physical prototype dimensions from virtual prototype dimensions it is possible to prevent the problem regarding differences between physical and virtual prototype dimensions. Using developed comparative pre-testings enables to avoid the situation, where the printed parts do not fit together properly because of the difference between physical and virtual prototypes dimensions.

Finally, proposed comparative table of 3 RP technologies can be used as back-up material for simplifying right decision making regarding rapid prototyping technology selections. Also the influence of parts positioning in 3D-printing process gives important knowledge for product developers for achieving more quality and resistant product for future testing processes and transportation. Thus, the main conclusions from chapter 3.5 are recommended to monitor and implement for minimizing and eliminating RP process failure risks during new product development.

On the other hand, after the e-manufacturing platform is in elaboration stage and new competence centre IMECC has been established connecting IT and engineering companies but also the Tallinn University of Technology, it is possible to achieve the proposed e-solution target for RP manufacturing service ordering together with cost estimation functionality. It enables to have a user-friendly e-service for rapid prototyping cost estimation and could help to outsource prototyping service from service provider who has long experiences in 3D printing technologies regarding prototyping.

In conclusion, we can point out that the proposed additional key performance indicators in innovation and NPD process can be taken into account in proposed solution regarding souvenirs, conference giveaways and other product family developments by small development teams and SME-s in order to achieve higher innovation capacity in these enterprises and thus meet business goals more effectively.

MAIN CONCLUSIONS

The consequences for discussed three main starting-points are the following:

1. Performance of RP methods was analyzed and investigated based on different prototypes of casing type details. RP "bottlenecks" have been investigated in more detail and suggestions for these prevention found. Therefore, one of the main key-driver for more productive product development is the ability to find solutions for preventing the failures that have occurred in development process earlier. The main conclusions for increasing the RP process quality are the following:
   - Differences between physical prototype dimensions compared to existing computer model (virtual prototype) dimensions can be diminished by using developed comparative pre-testing. In order to avoid the situation, where the printed 3D part dimensions differ from the CAD dimensions, it is suggested to analyze the uncertainty of arithmetic mean of physical prototype dimensions from virtual prototype dimensions. - Strength of prototype can be improved by printable part positioning in RP process. It was resulted, that positioning the parts in printing with IPT affects greatly the physical properties of the printed parts. It was discovered that upright positioning with post processing increases the maximum tensile strength about eight times and extension at break about three times. Using PLST, positioning the parts affects only the extension at break. It was increased about two times by positioning the part horizontally compared to upright positioning. - Comparison of different RP technologies enables to understand advantages and disadvantages of three most well-known RP technologies and thus enables to prevent failures in RP processes that could arise because of the improper RP technology selection.
   - Modularization implementation into CE conceptual model enables to make product development first phases more effective. Concurrent engineering process in product concept, rapid prototyping and testing phases allows due to modularization implementation for prototype design and analysis to occur at the same time and multiple times prior to actual deployment. Thus, modularization methodology approach is also suitable for apparatus industry where the variety of functions in electronic device can lead to need for changes already in RP phase. For that reason the product development time and the hidden costs for product reworks can be significantly reduced.

2. The influence of innovation to productivity has been analyzed from the employee's competences point of view and it was found that monitoring the

quality and quantity of employee's competences in engineering industry enterprises could lead to achieve competences development in organization. In addition in the current study RFID reader housing development case study proved that one important key-driver for risk and failures elimination in NPD process is the ability to use the developed expert tool for innovation capacity estimation in Estonian engineering industry enterprises.

3. Data management method implementation preconditions and possibilities have been analyzed in order to propose analysis method for machinery enterprises data analysis and for proposing novel solutions for increasing customer service quality in e-business. It was resulted:
   - Data mining implementation is useful for analyzing and updating existing databases in a process of development collaborative e-Manufacturing information system. Data model structure together with DM method implementation preconditions analysis enabled to understand that knowledge hidden in data has a profound impact on engineering as well because it can be used for complex analysis at a country level in sector of engineering industry. - Customer service quality can be improved by finding new approaches in e-solutions:
   The described toolset integrating RP cost model into e-manufacturing system and investigating the service usability by companies using data mining method opens new horizons in manufacturing.
   Data mining implementation is increasing productivity of management and innovation in the collaboration network. Integrating a data mining framework within the manufacturing information system enables to analyze enterprises' opportunities for manufacturing and its pre-calculations, find relations between enterprises, customers and subcontractors, and make consequences based on different data conjunctions.

To sum up, it should be pointed out that additional key-performance criteria in innovation and new product development process can be viewed also from the cleverness of:

- preventing RP bottlenecks in order to correct product development process;
- understanding modularization and concurrent engineering implementation necessity in the beginning of product development phases, enables enterprises to do cooperation between different counterparties more effectively due to modules of product;
- recognizing employee's knowledge and skills that are necessary in their specialty and owning the skill to create a development team by using innovation indicator necessary for achieving the expected innovative product development;
- understanding and having an overview about different data management possibilities that could lead to achieve higher customer satisfaction in online

service or could help to get an easier overview of all gathered data useful for future business objective determination or even for new business strategy development.

The main topics for the future research are as follows:

Arithmetic mean of physical prototype dimensions from virtual prototype dimensions have been investigated and compared between IPT and SST technology in case of smart dust housing detail development. On the other hand, in RFID reader housing development case study, differential measurements have been made with IPT and PLST technologies. As the comparisons between PLST and SST have not been implemented, it would be also interesting to compare the PLST with SST and find out, which of these RP technologies could have the smallest uncertainty of arithmetic mean of physical prototype dimension.

Secondly, data mining from product and development processes improvement perspectives have been handled and it has been discovered that their implementation could give powerful effect for machinery enterprises innovation and NPD productivity. Therefore, further implementation analysis has to be conducted.

After creating the main database (based on three existing databases: Metnet, Innomet and Innoclus) and eliminating "noisy" data, the aim is to use all these collected data about the enterprises and those technological capabilities and employee's skills for making and experimenting data mining models.

On the other hand, data mining application has to be used in case of e-manufacturing proposed for better customer servicing regarding RP manufacturing ordering service from TUT. As the e-manufacturing platform is in elaboration stage, a new competence centre IMECC has been established connecting IT and engineering companies but also the Tallinn University of Technology to achieve the proposed E-solution target for RP manufacturing service ordering together with cost estimation functionality. In order to have additional value for this purpose, DM method should be also implemented.

Therefore, further investigations regarding data mining have to be continued. Firstly, the data mining program implementation and database of machinery enterprises competences and technological skills are needed. Secondly, learning to use data mining models in order to attain the objects described in the current study is necessary. Currently the proposed effects of DM usage were assumed and have to be investigated in practice, as well.

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ABSTRACT

Nowadays business environment tends to be rapidly and non-linearly changing. Business objectives are strongly tied to management of unpredictability and chaos. Therefore, it is important to investigate additional key-drivers that could help to achieve higher innovation capacity in enterprises. In current research based on best practice approach Estonian SME-s have been taken into account in order to research several aspects of New Product Development (NPD) and innovation. Three main starting points have been handled in order to find key-drivers for making the product development process more effective.

Firstly, it is known that Rapid Prototyping (RP) is recognized as a significant technology for future product development. Today more and more manufacturers experience immense pressure to provide a greater variety of complex products in shorter product development cycle. RP, as the name implies, should involve prototyping parts rapidly. In current practice there have been projects where rapid prototyping failure risks are related to prototyping accuracy or printed part strength problems. Therefore, different case studies have occurred in our research for finding how these problems could be prevented in future product development projects. Different RP technologies have been implemented and investigated based on best-practice approach. Most well-known 3D printing technologies have been compared and comparative table proposed as back-up material for future RP technology selection. On the other hand, the case studies have been executed by taking into account also concurrent engineering and modularization for simplifying the product development process and accelerating the development speed already in the beginning of the product development phases. In addition, tensile strength analysis of printed parts has been analyzed and improvement suggestions for more effective RP development process proposed.

Secondly, for today there is a new broad view of the innovation process – it is essential and necessary for organizations dealing with the educational dimensions of innovation. Thus, organization's chiefs not only have to provide physical capital (R&D and technology infrastructure) but should also deal with enhancing human capital (training of workers) and social capital (i.e. encouraging the formation of trust based relationships between other firms). Therefore, the innovation capacity of employees and entrepreneurs from the competences point of view has been analyzed in the engineering industry sector in Estonia. It was necessary for understanding innovation estimation importance for enhancing more effective results in product development processes. Therefore, the influence of innovation to productivity has been investigated from employee´s competences point of view. Thus, it was also important to develop the solution for selecting product developers so that the innovation capacity by

organization product development team can be ensured. An expert system has been proposed for estimating innovation capacity of the team/company.

Finally, Data Mining (DM) implementation for manufacturing area has been analyzed. New possibilities in data management regarding novel solution implementations in engineering sector have been proposed for finding key factors for more user-friendly and quality e-services. Thus, e-manufacturing solution opportunities from data management implementation point of view have been handled regarding customer service improvement possibilities.

Thus, the research is about additional key-drivers that should be considered for making rapid prototyping, innovation capacity estimation and data management in organization more effective in order to ensure higher innovation capacity. Main conclusions from the research should provide additional surplus value for companies and help to find useful methods for improving new product development process and achieve higher innovation capacity. In addition, this research describes and points out how customer satisfaction can be improved by using new data management possibilities in e-business.

Keywords: New Product Development, Rapid Prototyping, Concurrent Engineering, Modularization, Data Management

KOKKUVÕTE

Uue toote arenduse protsessi juhtimine nõuab oskusi õigete otsuste tegemiseks ning seetõttu on oluline erinevate võtmeindikaatorite jälgimine ja nende rakendamine ettevõtte tootearenduse protsessis. Firma innovatsiooni suutlikkuse hindamine omab olulist tähtsust mitte ainult ettevõtte juhtimise seisukohast lähtuvalt, vaid on oluliseks eelduseks ka ettevõtte konkurentsivõime tagamiseks ning toodete/teenuste tõhusamaks edasiarenduseks. Senini on ettevõtetes oluliste võtmeindikaatoritena käsitletud näiteks tulu investeeringutelt, tulude kasvu, aega, mis kulub uue tootega turule jõudmiseks jne. Need loetletud indikaatorid ei ole aga ainsad olulised näitajad, mida tuleks arvesse võtta ärieesmärkide efektiivsemaks saavutamiseks. Täiendavalt on oluline käsitleda võtmekriteeriumitena ka näiteks indikaatoreid, mis aitavad kaasa efektiivsema tootearenduse protsessi tagamisele ja panustavad ettevõtte parema innovatsiooni suutlikkuse saavutamisele võimaldades seeläbi oluliselt vähendada tootearendusprotsessi ebaõnnestumise riske ja muuta kogu tootearenduse protsessi veelgi tõhusamaks.

Antud töös on uuritud innovatsiooni ja uue toote arenduse protsessi panustavaid võtmeindikaatoreid. Reaalselt läbi viidud kasutusjuhtude põhjal on uuritud erinevaid kiirprototüüpimise võimalusi tootearendusprotsessis ning analüüsitud, kuidas samaaegsete projekteerimistööde ja modulariseerimise metoodikate rakendamine tootearenduse esmastes etappides nagu toote kontseptsiooni väljatöötamise, kiirprototüüpimise ja testimise faasis, võib kaasa aidata kogu tootearendusprotsessi tõhusamaks muutmisele. Lisaks on oluliste kriteeriumitena vaadeldud ettevõtte innovatsiooni suutlikkuse hindamist ning oskust leida uudseid lahendusi andmetöötlusvõimaluste rakendamisel tõstmaks klientide rahulolu ning saavutamaks seeläbi tugevamat konkurentsieelist turul.

Sellest tulenevalt on antud doktoritöö jagatud kolme peamisesse ossa, kus erinevaid tootearenduse protsessi ja innovatsiooni panustavaid indikaatoreid vaadeldakse eraldi teemadena ning ka üksteisega koos, moodustades tervikpildi. Antud töös käsitletakse erinevaid enimtuntuid kiirprototüüpimise tehnoloogiaid, modulariseerimise ja samaaegsete projekteerimistööde metoodikaid ning uudseid lahendusi nii ettevõtte innovatsiooni suutlikkuse hindamiseks kui erinevate andmetöötlusvõimaluste rakendamiseks erinevate väljapakutud e-lahenduste näidetel.

Töö esimeses osas käsitletakse peamisi kiirprototüüpimisel tekkinud probleeme, analüüsitakse neid ning tehakse ettepanekuid 3D prototüüpimise protsessi parendamiseks. Teises osas keskendutakse innovatsiooni suutlikkuse hindamisele võttes arvesse ettevõtte töötajate ametialaseid oskuseid. Samuti pakutakse välja hinnanguline ekspertsüsteem, mis aitab analüüsida ettevõtte töötajate oskustasemeid ja moodustada tootearendusmeeskonda selliselt, et innovatsioonisuutlikkus ettevõttes oleks tagatud. Töö viimases osas aga keskendutakse erinevate andmetöötlusvõimaluste rakendamisele ning analüüsitakse andmekaevanduse rakendamise eeltingimusi masinaehitussektoris lähemalt. Samuti uuritakse ja pakutakse välja erinevaid lahendusi klienditeeninduse kvaliteedi tõstmiseks erinevatele e-lahenduse näidetele baseerudes. Lõpuks tuuakse välja antud uurimistöö tulemusena leitud võtmeindikaatorite rakendamise näide konkreetse kasutusjuhtumi põhjal. Viimane peatükk seega annab ülevaate, kuidas antud töö järelduste rakendamine aitab muuta tootearendusmeeskondade töö tootearendusprotsessis senisest veelgi efektiivsemaks.

Töö põhilised järeldused 3 peamist lähtepunkti arvesse võttes on järgmised:

1. Doktoritöös sai võrreldud erinevaid enimlevinud 3D kiirprototüüpimise tehnoloogiad ja baseerudes reaalsetele tootearenduse juhtudele sai välja töötatud erinevate toodete korpused kasutades erinevaid 3D printimise tehnoloogiaid nagu IPT, SST ja PLST. Seega, reaalsete kasutusjuhtude põhjal sai uuritud lähemalt kiirprototüüpimisel tekkinud "pudelikaelu" ja väljapakutud nende vältimise võimalusi edaspidisteks prototüübi valmistamise protsessideks. Selleks, et olla edaspidistes tootearendusprotsessides veelgi edukam, on oluline teada ebaõnnestumise põhjuseid ja osata neid edaspidistes prototüüpimise protsessides vältida. Seega, olulised indikaatorid, mida prototüübi valmistamisel arvesse tuleks võtta on järgmised:

- **Virtuaalse ja füüsilise prototüübi mõõtmete erinevusi on võimlik vältida kasutades töös välja pakutud võrdlevat eeltestimise metoodikat.** Selleks, et vältida olukorda, kus prinditud prototüübi (füüsilise prototüübi) mõõtmed ei erineks joonisel toodud mõõtmetest (virtuaalse prototüübi mõõtmetest), on soovitatav teada füüsilise prototüübi mõõtmete keskmist kõrvalekallet virtuaalse prototüübi mõõtmetest. See annab võimaluse mehaanika inseneridele vähendada prototüübi mõõtmeid ennem 3D-printimist ja vältida seeläbi olukorda, kus väljaprinditud detailid printimisjärgselt omavahel kokku ei sobi.
- **Väljaprinditava detaili positsioneerimine printimisprotsessis omab olulist mõju detaili füüsilistele omadustele.** Tööst järeldus, et IPT tehnoloogiaga väljaprinditud detailid, mis olid asetatud püstisesse asendisse ja kaetud spetsiaalse pindkatte vahendiga, olid füüsilistest omadustest tõmbetugevuse osas keskmiselt 8 korda enam vastupidavamad ja elastse pikenemise osas 3 korda kui horisontaalselt prinditud detailid. Seevastu, kasutades PLST printimistehnoloogiat, ilmnes et detaili asetus printimisprotsessis omab tähtsust üksnes elastsele pikenemisele. See oli kaks korda enam tagatud, kui detail oli asetatud horisontaalsesse asendisse. Teadmine detaili asetustest erinevate printimistehnoloogiate puhul on oluline detaili vastupidavuse tagamise seisukohast lähtuvalt. Kui 3D-printimisel valminud prototüüpi kasutatakse olulise detailina koostus või on oluline selle vastupidavus transportimisel, tuleb arvestada, et

väljaprinditud detaili füüsilised omadused on tagatavad detaili asetusega printimisel.

- **Erinevate enimlevinud kiirprototüüpimisel kasutatavate 3D printimistehnoloogiate võrdlev analüüs võimaldab mõista erinevate tehnoloogiate eeliseid ja puudusi.** Ülevaade kolmest enimlevinud tehnoloogiast võimaldab teha edaspidistes tootearendusprotsessides õigeid tehnoloogia valikuid lähtudes erinevatest väljapakutud kriteeriumitest ning võimaldades seeläbi vältida varasemalt kiirprototüüpimisel tekkinud probleeme.
- **Samaaegsete projekteerimistööde ja modulariseerimise metoodikate rakendamine tootearenduseprotsessi algfaasides omab olulist tähtsust järgmistel põhjustel:**
  - **Modulariseerimise metoodika rakendamine koos samaaegsete projekteerimistööde metoodikaga juba tootearenduse esmastes etappides võimaldab projekteerida, analüüsida ja testida toote muudatusi samaaegselt juba toote prototüüpimisel**. Seega on võimalik vähendada tootearenduse aega ja kulusid, mis kaasneksid toote ümbertegemisega. Erinevate valdkondade inseneride kaasamine toetab paralleelselt toote disaini ja kogu arenduse protsessi, kus insenerid saavad omavahel läbi arutada iga muudatuse ja selle töösse võtta omas valdkonnas paralleelselt teiste valdkondade inseneridega. Samaaegsete projekteerimistööde rakendamine koos toote modulariseerimisega võimaldab seega muuta prototüübi valmistamise protsessi efektiivsemaks ja seeläbi vähendadaka tootearendusega kaasnevaid kulusid ning jõuda uuenenud tootega turule oluliselt kiiremini kui seda võimaldaks prototüübi valmistamine erinevate valdkonda inseneride poolt eraldi tootearendusetappide kaupa.
  - Modulariseerimine võimaldab prototüüpida toodet moodulite kaupa üksteisest eraldi ja seega valmistada prototüüpi oluliselt kiiremini ning parema kvaliteediga, sest igat moodulit on võimalik muuta eraldi ilma teistele moodulitele funktsionaalset mõju avaldamata.

2. Innovatsiooni suutlikkuse mõju ettevõtte tootlikkusele sai analüüsitud ettevõtte töötajate oskustasemetest lähtuvalt. Analüüsist järeldus, et **ettevõtte töötajate oskustasemete monitooring ametikohtade lõikes masinaehituse, metallitöötluse ja aparaadiehituse sektoris aitab oluliselt kaasa kompetentside edasiarengule organisatsioonis. Innovatsiooni suutlikkuse hindamine väljatöötatud ekspertsüsteemi abil on oluliseks abivahendiks parima võimaliku tootearendusmeeskonna komplekteerimisel**. Väljatöötatud ekspertsüsteem leidis rakendust RFID lugeja korpuse arendusprotsessis ja selgitas, et selle rakendamine tootearendusmeeskonna innovatsiooni suutlikkuse hindamiseks ja tootearendusmeeskonna komplekteerimiseks omab olulist tähtsust, et saavutada püstitatud eesmärgid võimalikult efektiivselt ja et vältida tootearendusprojektis ilmnevaid riske. Seega, olulise indikaatorina

tootearendusprojekti riskide maandamiseks ja ebaõnnestumiste elimineerimiseks võib käsitleda antud töös väljatöötatud hinnangulist ekspertsüsteemi, mille rakendamine aitab oluliselt kaasa ettevõtte innovatsiooni suutlikkuse tagamisele.

3. Töös sai analüüsitud erinevaid andmetöötluse rakendamise võimalusi, et välja pakkuda sobivat analüüsi metoodikat masinatööstusettevõtete andmete analüüsiks ja leidmaks uudseid lahendusi klienditeeninduse kvaliteedi tõstmiseks e-äris. Seega sai uuritud detailsemalt andmekaevanduse rakendamise eeltingimusi masinatööstusettevõtete andmete näitel ja väljatöötatud andmestruktuuri mudel, mis võimaldaks tulevikus teostada olulisi andmeanalüüse. Analüüsi tulemusena selgus, et senini peamiselt küll finants- ja kaubandussektoris laialt levinud andmeanalüüsi metoodika - andmekaevandus, on sobilik ka inseneri valdkonnas, kus andmetesse peidetud teadmised omavad olulist tähtsust ka töötleva tööstuse sektorites. Seega, andmekaevanduse rakendamine omab olulist tähtsust näiteks koostöövõrgustiku loomisel ühtse e-tootmise infosüsteemi arendamiseks. Teiseks, klienditeeninduse kvaliteeti saab parendada andmetöötlusvõimalustes uute suundade leidmisel, näiteks läbi e-teeninduse kvaliteedi tõstmise:

- Analüüsitud sai e-tootmise võimalusi tööstussektoris koos andmekaevanduse rakendamisega ning välja sai pakutud veebipõhine lahendus prototüübi valmistamise teenuse osutamiseks. Kirjeldatud töövahend integreerib endas nii prototüübi valmistamise kulude hinnangu andmise teenuse tellijale kui ka võimaldab teenuse osutajal endal analüüsida teenuse kasutamisaktiivsust prototüübi tellijate seas. Seega võib välja tuua, et **andmekaevanduse rakendamine omab olulist tähtsust ka tööstussektoris, kus informatsioonitöötlus avaldab olulist mõju ettevõtte juhtimisele teenuse osutamisel ning võimaldab tagada oluliselt efektiivsema koostöö kliendi ja teenuse osutaja vahel**. Integreerides andmekaevanduse võimalusi tootmise infosüsteemi, on võimalik analüüsida ettevõtete võimalusi ja pakkuda hinnangulisi eelkalkulatsioone või leida erinevaid seoseid nii ettevõtete, nende klientide ja alltöövõtjate vahel kui ka teha olulisi järeldusi baseerudes erinevatele andmeseostele, mida andmekaevandus koos ettevõtete infosüsteemiga võimaldab.

Kokkuvõttena võib välja tuua, et täiendavate võtmeindikaatoritena, mis aitavad panustada innovatsiooni ja uue toote arenduse protsessi, on käsitletavad oskusest:

- vältida kiirprototüüpimise seniseid „pudelikaelu", et parendada tootearenduse protsessi;

- mõista modulariseerimise ja samaaegsete projekteerimistööde metoodikate rakendamise olulisust juba tootearenduse protsessi esmastes etappides;

- hinnata ettevõtte töötajate teadmisi ja oskusi, mis on vajalikud nende ametialaste ülesannete täitmiseks ning komplekteerida innovatsioonisuutlik tootearenduse meeskond kasutades selleks töös väljatöötatud innovatsiooni indeksit;
- mõista ja omada ülevaadet erinevatest andmetöötlusvõimalustest, mis aitavad tagada kliendirahulolu ja omavad olulist tähtsust mõistmaks ettevõtete andmeid, et parendada juhtimisprotsesse või töötada välja uusi ärieesmärke.

Edaspidised uurimissuunad antud teemaga seoses on järgmised:

Füüsilise prototüübi mõõtmete keskmine kõrvalekalle virtuaalse prototüübi mõõtmetest sai analüüsitud võrreldes IPT ja SST 3D-printimise tehnoloogiaid targa tolmu korpuse arenduse näitel. Teisest küljest, RFID lugeja korpuse arendusel sai käsitletud mõõtmete erinevust võttes arvesse IPT ja PLST tehnoloogiaid. Seega, PLST ja SST tehnoloogiate omavaheline võrdlus ei leidnud rakendust ja omab samuti tähtsust ning pakub huvi edasiseks analüüsiks, et teada saada, milline kahest tehnoloogiast omab vähimat keskmist kõrvalekallet füüsilise ja virtuaalse prototüübi mõõtmete osas.

Töös sai uuritud andmekaevanduse rakendamise eeltingimusi masinaehitusettevõtete andmete analüüsiks ja ettevõtete koostöövõrgustiku loomiseks ning leitud, et selle metoodika rakendamine omab olulist mõju ka masinatööstusettevõtete innovatsioonisuutlikkusele ja uue toote arendamise protsessidele. Seega on kindlasti oluline edasiste analüüside rakendamine töös kogutud andmete analüüsiks. Pele seda, kui reaalne andmebaas väljatöötatud andmestruktuuri mudeli põhjal on koostatud ja andmed korrastatud, on eesmärk ettevõtete oskustest ja tehnoloogilistest ressurssidest kogutud andmeid kasutada andmemudelite koostamiseks ja oluliste seoste ning mustrite leidmiseks nendest andmetest. Lisaks on huvi analüüsida väljapakutud prototüübi tellimise teenuse kasutusaktiivsust lähemalt ja leida olulisi järeldusi, mis võimaldaks antud teenust edasi arendada. Seega, peale seda kui e-tootmisplatvorm on töösse rakendatud, on huvi andmekaevanduse rakendamise osas olemas ning töö käigus kogutud andmete edasine töötlus ning analüüs kindlasti vajalikud.

Peamised edasised suunad seega seisnevadki peamiselt andmekaevanduse võimaluste rakendamises praktikas kohe peale seda kui töös leitud eeltingimused on selleks täidetud. Senini väljapakutud andmetöötlusvõimalustest saadav kasu on eeldatav ja hinnanguline ning vajab kindlasti analüüsimist ka praktikas, et kinnitada senised oletused andmekaevanduse efektiivsusest töös väljapakutud lahendustele.

APPENDIX

Data definitions for joined database structure

DATA FROM DIFFERENT DATABASES	**DESCRIPTION**
Data from Metnet	
Enterprise_Id	Each enterprise is given specific number (ID). It helps to join other data related to a certain enterprise
Enterprise_Name	Enterprise name registered in Commercial Register. Each Entetrprise_Id is related to a certain Enterprise_Name
Sector_Id	Sector ID classifies enterprises into four main groups: educational institutions, suppliers of materials, equipment and tooling suppliers and production companies. Each group is given a certain number (ID).
Sector_Name	Sector name related to certain Sector_Id. For example: educational institutions=1. Suppliers of materials=2. Equipment and tooling suppliers=3 producing companies=4
Geographic_Localisation_Id	Geographic localization ID classifies enterprises into five main groups: West- Estonia, North- Estonia, North- Estonia, Central- Estonia, South- Estonia and East- Estonia. Each localization is given a certain number (ID).
Geographic_Localisation_Name	Geographic localization name that is related to certain Geographic_Localisation_ID. For example: West- Estonia=1. North- Estonia=2. Central- Estonia=3. South- Estonia=4 East- Estonia=5.
Registration_Number	Registration code of enterprise from Central Commercial Register.
Address	Address of enterprise (street)
County	Address of enterprise (county)

Town/Borough	Address of enterprise (town or borough)
Zip	Address of enterprise (zip code)
Phone	Contact phone of enterprise
Fax	Fax of enterprise
Homepage	Homepage address of enterprise
E-mail	Contact e-mail of enterprise
Management_Person	Contact person name who is the member of the board.
Management_Person_Position	The position of contact person.
Management_Person_Phone	Phone number of management person.
Management_Person_e-mail	E-mail of management person.
Contact_Person	Main contact person from enterprise (name).
Contact_Person_Position	The position of main contact person.
Contact_Person_Phone	Phone number of main contact person.
Contact_Person_e-mail	E-mail of main contact person.
Field_of_Activity_Id	Field of activity ID classifies enterprise's activities into different groups. Each activity is given a certain number (ID). For example: 1=Subcontracting for car industry
Field_of_Activity_Name	Field of activity name that is related to a certain Field_of_Activity_Id (subcontracting for car industry=1).
Product_Id	Product ID classifies enterprise products into different groups. Each product is given a certain number (ID).
Product_Name	Product name related to a certain Product_Id. For example: Stamped and formed products=1. Assemblies=2. Welded constructions=3. Mechanically treated steel- and aluminum products=4 and etc.
Technology_Id	Technology ID is related to a specific Technology_Name that shows which technologies are provided by enterprise. Each technology is given a certain number (ID).
Technology_Name	Technology name that is related to a certain Technology_Id. For example: Mechanical treatment of steel- and aluminum products=1.

	Powder coating=2 and etc.
R&D_Id	R&D ID is related to a specific R&D_Name that shows which research and development works are related to an enterprise. Each R&D work is given a certain number (ID).
R&D_Name	R&D name that is related to a certain R&D_Id. For example: Machinery=1. Production Management=2. Product Development=3 and etc.
Continual_Education_Id	Continual education ID is related to a specific Continual_Education_Name that explains, in which educational field enterprise is sustainable. Each education is given a certain number (ID).
Continual_Education_Name	Continual education ID is related to a certain Continual_Education_Id. For example: Development of Machine and Mechatronic Systems=1. Design and Manufacturing of Products and their Components=2. Technology of Rapid Prototyping=3 , Design and Manufacturing of Tools and Jigs=4. CAD/CAM Systems=5 and etc.
Materials_Id	Materials ID is related to a specific Materials_Name that explains, which materials can be processed by enterprise. Each material is given a certain number (ID).
Materials_Name	Materials name is related to a ceratin Materials_Id. For example: Corrugated metal sheet=1. Cold rolled sheet: sheet and rolls=2 and etc.
Specification_of_Materials_Id	Specification of materials ID is related to a specific Specification_of_Materials_Name that describes material in more detail. Each specification of material is given a certain number (ID).

Specification_of_Materials_Name	Specification of materials name is related to a ceratin Specification_of_Materials_Id. For example: IPE/ HEA/ HEB beams=1. Hot and cold rolled plate=2. Wire=3 and etc.
Customer_Id	See Enterprise_Id.
Customer_Name	See Enterprise_Name.
Market_Id	Market Id is related to a specific Market_Name explaining on to which market the enterprise is related. Each market is given a certain number (ID).
Market_Name	Market name is related to a certain Market_Id. For example: Estonia=1. Russia=2. Baltic states=3.
Turnover_EEK	Annual turnover of enterprise in EEK.
Turnover_EUR	Annual turnover of enterprise in EUR.
Export_Share_of_Turnover	Enterprise export share of turnover.
Nbr_of_Employees	Number of employees in enterprise.
Nbr_of_Students	Number of students in enterprise.
Year_of_establishment	Enterprise establishment year.
Working_Language_Id	Working language ID is related to a specific Working_Language_Name that shows which language is used in enterprise as working language. Each language is given a certain number (ID).
Working_Language_Name	Working language name related to a certain Working_Language_Id. For example: Estonian=1. Russian=2. Finnish=3. German=4. English=5.
Quality_Management_Certificate_Id	Quality management certificate ID is related to a specific Quality_Management_Certificate_Name that explains which quality certification enterprise has. Each quality management certificate is given a certain number (ID).

Quality_Management_Certificate_Name	Quality management certificate name is related to a certain Quality_Management_Certificate_Id. For example ISO 9001:2000=1 and etc.
Data from Innomet	
Vocation_Id	Vocation ID is related to a specific Vocation_Name that shows which positions are owned in enterprise. Each vocation is given a certain number (ID).
Vocation_Name	Vocation name is related to a certain Vocation_Id. For example: Development manager=1. Welder=2. CAD engineer=3 and etc.
Skill_Type_Id	Skill type ID is related to a specific Skill_Type_Name that classifies enterprise employee skills into 4 main groups: professionalisms, personal identities, base skills and general skills. Each skill is given a certain number (ID).
Skill_Type_Name	Skill type name is related to a certain Skill_Type_Id. For example: Professionalisms=1. Personal identities=2. Base skills=3. General skills=4.
Existent_Skill_Level_Id	Existent skill level ID is related to a specific Skill_Level_Name that explains on which level enterprise employee skills are in five-point scale.
Necessary_Skill_Level_Id	Necessary skill level ID is related to a specific Skill_Level_Name that explains on which level enterprise employee skills are expected to be in five-point scale.
Skill_Level_Name	Skill level name is related to a certain Existent_Skill_Id or Necessary_Skill_Level_Id, where in five-point scale the meanings are the following: the highest=1. High=2. Medium=3. Low=4. The lowest=5.

Competence_Id	Competence ID is related to a specific Competence_Name that is part of one vocation and will be measured with existent and necessary skill levels. Each competence is given a certain number (ID).
Competence_Name	Competence name is related with concrete Competence_Id. For example: Knowing ERP systems=1. Knowing Simulation technologies=2 and etc.
Dada from Innoclus	
Technical_Parameter_Id	Technical parameter ID is related to a specific Technical_Parameter_Name that classifies enterprise activities into main groups. Each technical parameter is given a certain number (ID).
Technical_Parameter_Name	Technical parameter name is related to a certain Technical_Parameter_Id. For example mechanical treatment=1 and etc.
Technical_Parameter_Type_Id	Technical parameter type ID is related to a specific Technical_Parameter_Type_ Name that presents different subgroups of Technical_parameter_ID/ Technical_Parameter_Name. E.g. mechanical treatment can have the following subtypes: sheet metal processing, welding, turning, milling, drilling and etc.
Technical_Parameter_Type_Name	Technical parameter type name is related to a certainTechnical_Parameter_ Type_Id. For example sheet metal processing=1. Welding=2. Turning=3. Milling=4 and etc.
Technical_Parameter_Status_Id	Technical parameter status ID is related to a specific Technical_Parameter_Status_ Name that shows whether the technical resource is available from the enterprise. Each technical parameter status is given a certain number (ID).

Technical_Parameter_Status_Name	Technical parameter status name is related to a certain Technical_Parameter_Status_Id. For example: yes=1 and no=2, where yes means that technical resources are available and can be subcontracted from the enterprise and no that it is not possible because of lack of free resources.

CURRICULUM VITAE

1. Personal data

Name	Birthe Matsi
Date and place of birth	11.08.1982. Pärnu

2. Contact information

Address	Rahu street 14. Tallinn
Phone	+372 5108926
E-mail	birthe.matsi@gmail.com

3. Education

Educational institution	Graduation year	Education (field of study/degree)
Tallinn University of Technology	2006	Product development, MSc
Tallinn University of Technology	2005	Product development, BSc
Kilingi-Nõmme Secondary School	2001	Secondary education

4. Language competence/skills (fluent; average, basic skills)

Language	Level
Estonian	Mother tongue
English	Average skills
Russian	Average skills

5. Special Courses

Period	Educational or other organisation
10.09-11.09.2007	“Clementine and Data Mining”, Janne Koljonen, Lauri Salminen
06.11-23.11.2006	“Technology and Innovation Policy”, Katrin Männik, Kitty Kubo
26.09-31.10.2006	“Legal Protection of Intellectual Property”, Kersti Peekma, Kiira Parre

18.10. 2006	„ Legal Protection of Inventions and Trademarks", Elle Mardo, Peter Cordsen; Ardo Urmet, Jüri Käosaar, Ingrid Matsina, Mart Repnau, Heli Pihlajamaa
02.10-06.10.2006	„ Technology transfer and innovation techniques and tools", Miretta Giacometti, Gillian Mcfadzean, Magnus Klofsten, Richard Reeves, Heinz Fiedler
30.08-31.08.2006	"Science Marketing", Judy Marcure; Thomas Baaken

6. Professional Employment

Period	Organisation	Position
06.2006- 03.2007	Tallinn University of Technology, Technology and Innovation Centre	Technology transfer officer
03.2007- 01.2009	AS Hansapank	Development specialist
01.2009- 01.2010	AS Swedbank	Development manager of e-channles
01.2010-	AS SEB Pank	Development manager of e-services

ELULOOKIRJELDUS

1. Isikuandmed

Ees- ja perekonnanimi	Birthe Matsi
Sünniaeg ja –koht	11.08.1982. Pärnu
Kodakondsus	Eesti

2. Kontaktandmed

Aadress	Rahu 14. Tallinn
Telefon	+372 5108926
E-posti aadress	birthe.matsi@gmail.com

3. Hariduskäik

Õppeasutus	Lõpetamise aeg	Haridus
Tallinna Tehnikaülikool	2006	Tootearendus, Tehnikateaduste magistrikraad
Tallinna Tehnikaülikool	2005	Tootearendus, Tehnikateaduste bakalaureuse kraad
Kilingi-Nõmme Gümnaasium	2001	Keskharidus

4. Keelteoskus (alg-, kesk- või kõrgtase)

Keel	Tase
Eesti	emakeel
Inglise	kesktase
Vene	kesktase

5. Täiendusõpe

Õppimise aeg	Täiendusõppe läbiviija nimetus
10.09-11.09.2007	“Clementine ja andmekaevandus”, Janne Koljonen, Lauri Salminen
06.11-23.11.2006	“Tehnoloogia- ja innovatsioonipoliitikad”, Katrin Männik, Kitty Kubo
26.09-31.10.2006	“Leiutiste ja kubamärkide kaitse”,

	Kersti Peekma, Kiira Parre
18.10. 2006	„Leiutiste ja kubamärkide kaitse”, Elle Mardo, Peter Cordsen; Ardo Urmet, Jüri Käosaar, Heli Pihlajamaa, Ingrid Matsina, Mart Repnau
02.10-06.10.2006	„Tehnoloogiasiirde ja inniovatsiooni tehnikad”, Miretta Giacometti, Magnus Klofsten, Gillian Mcfadzean, Richard Reeves, Heinz Fiedler
30.08-31.08.2006	“Teadustegevuse turundamine”, Judy Marcure; Thomas Baaken

6. Teenistuskäik

Töötamise aeg	Tööandja nimetus	Ametikoht
06.2006- 03.2007	TTÜ Tehnoloogia ja innovatsioonikeskus	Tehnoloogiasiirde spetsialist
03.2007- 01.2009	AS Hansapank	Arendusspetsialist
01.2009- 01.2010	AS Swedbank	E-kanalite arendusjuht
01.2010-	AS SEB Pank	E-teenuste arendusjuht

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.

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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.

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

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

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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.
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20. **Grigori Nekrassov**. Development of an Intelligent Integrated Environment for Computer. 2004.
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26. **Renno Veinthal**. Characterization and Modelling of Erosion Wear of Powder Composite Materials and Coatings. 2005.
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